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Automatic Color

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I. INTRODUCTION.

This thesis will discuss and present some practical solutions to the problem of variations in color and hue in the reproduction of the color picture in television receivers. It has been a very common experience of television viewers, that in order to get a good color picture one must frequently adjust the color control, the hue control or both controls. The frequency of these adjustments depends on the quality and standards of color television transmission that are maintained by the networks and television stations. It has been observed that few transmitters are maintaining these standards at a desirable quality. As a result television receiver manufacturers are tempted to provide some automatic circuits to compensate for these transmission errors. The main theme of this thesis is to present a practical soloution to the transmission errors.

This thesis has been organized into five chapters, including this introduction as chapter 1. The second chapter briefly describes color television transmission and reception, N.T.S.C (National Television Systems Committee) color television standards and the signal distortion in the television video signal. The purpose of this chapter is to introduce the reader to the basic concepts of color television. These will be helpful in understanding the presentation of automatic color control.

The third chapter describes the various system that have been used at the receiver to compensate for the signal distortion related to color saturation. The performance of each system in handling various color scenes is discussed. It is shown that in absence of a reliable color amplitude reference from the transmitter an exact and accurate automatic color saturation control can not be built.

The fourth chapter describes the various system which have been used in television receivers to compensate for the signal distortion related to color hue. The main objective of the automatic hue correction circuit is to reduce the variation in hue of the fleshtone colors caused by the signal distortion. Minimization of variations in hue of fleshtone colors is selected because viewers are most sensitive to changes in these colors. Automatic hue correction introduces hue distortion to other colors. Here again, due to absence of a reliable color hue reference from the transmitter, an exact and accurate automatic color hue control can not be built.

The fifth chapter, written as the conclusion of this thesis, describes the Electronic Industries Association (E.I.A) proposed " Vertical Interval Reference " (V.I.R) signal. This signal, which is inserted near the end of the vertical interval, is intended to improve color television transmission and eliminate the need for automatic color saturation and automatic hue control circuits at the receiver.

II. N.T.S.C. COLOR T.V STANDARD

2-1 Introduction :

In television, the video signal is produced by successively scanning different portions of the scene by a camera tube that at each instant develops a voltage proportional to light intensity. The varying voltage that results from this scanning process is amplified and then modulated upon a radio frequency carrier wave that is radiated . The television receiver synthesizes the original scene on the fluorescent screen of a cathode ray tube by causing the cathode ray spot to trace over successive portions of the reproduced scene in accordance with the scanning of the original scene, while at the same time varying the brightness of the spot in accordance with the envelope amplitude of the received signal. When the scanning process is carried out with sufficient rapidity, the illusion of continous motion is achieved.

The standard television picture frame employed in the U.S.A. has a ratio of width to height of 4 :3. A picture frame consists of 525 lines, and 30 frames are transmitted in each second. The image flicker from a television picture can become quite noticeable at a 30 cycle frame rate. The technique used to increase the scanning rate, without increasing the number of scanning lines is called "Interlaced scanning".

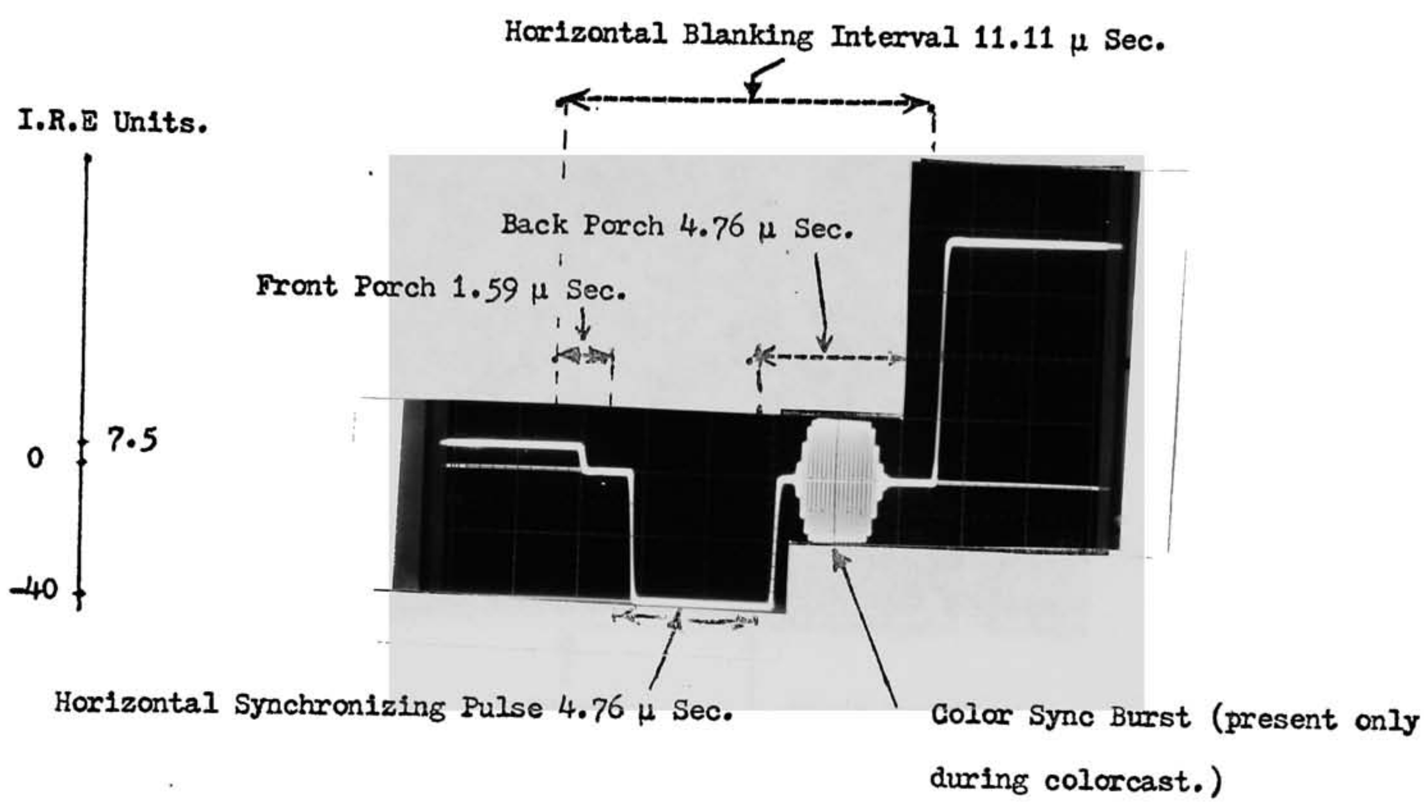
The scanning spot starts in the upper left hand corner and travels at a uniform rate from left to right along a line at a constant downword slope. When the end of the line is reached, the scanning spot quickly returns to the left. During this return interval the spot is blanked out. The scanning spot has then completed line number 1. The next line begins from left side at a level that is one line below the end of the previous line; therefore this line is number three. The scanning spot continues to travel back and forth across the tube from left to right, and at the same time it moves downward at a constant rate. When the bottom of the picture is reached the "Odd field" is completed, and then the spot quickly returns to the top of the picture tube while maintaining the back and forth horizontal line motion without interruption. During this vertical return interval the spot is blanked out. The scanning spot is then ready for the next field, but this time the scanning spot starts from the second line and travels through all even number lines. This field is called the "Even field".

Each frame has two fields and each field has 262.5 lines. Because each field contains a half line, the next field lies between the lines of the first field. Thus successive fields are interlaced. Interlacing makes it possible to avoid flicker while using the lowest repetition frequency for the picture that will satisfactorily portray motion. By interlacing a flicker rate of 60 cycles is achieved, which is too high to be perceptible. At the same time, the picture is repeated only 30 times a second.

During the horizontal and vertical return intervals the picture tube is made inoperative by means of the blanking pulses which are transmitted by modulating the carrier wave with pulses that are at the voltage level lower than that corresponding to "Black voltage". The horizontal blanking pulse is about 11.1 μsecond long, and the vertical blanking pulse is about 1250μsecond long.

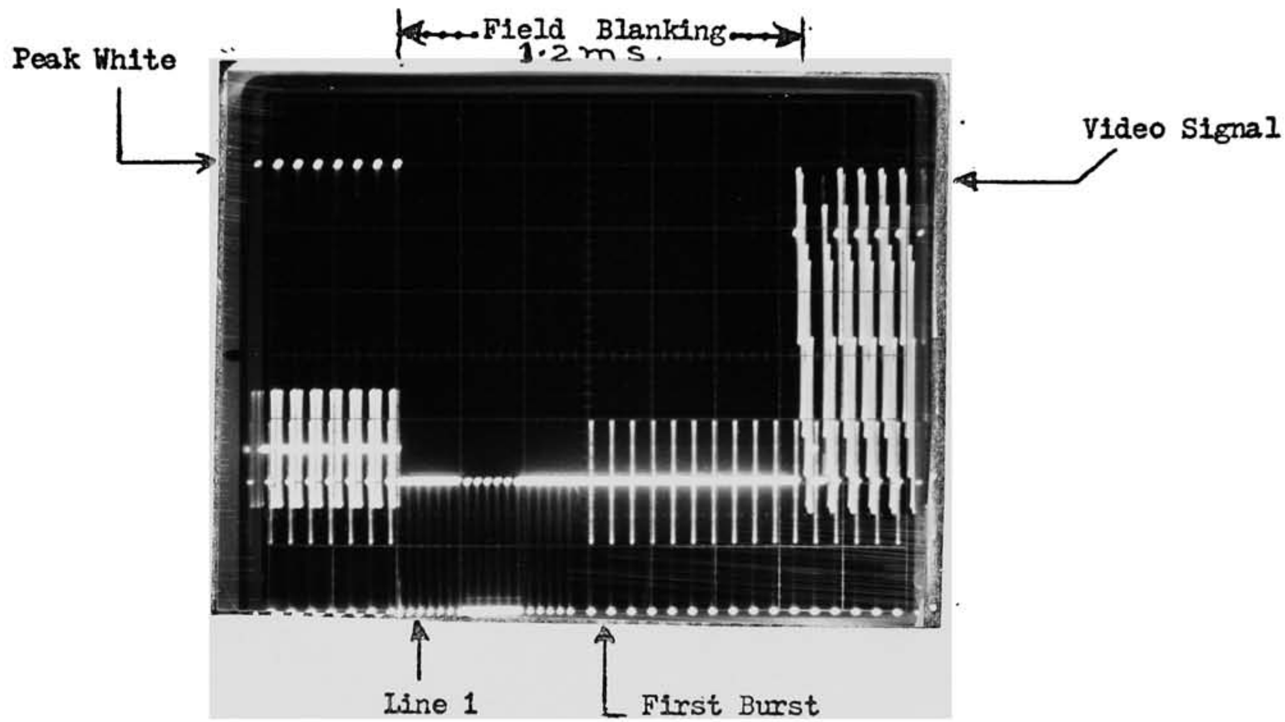
Synchronization between the scanning operation at the transmitter and at the receiver is accomplished by means of special pulses that are generated at the transmitting station and modulated on the radiated carrier wave. Horizontal or line synchronization pulses are about 5μsecond long and are superimposed on the horizontal blanking pulses in the manner shown in Figure 2-1 (a). The vertical synchronizing pulse is distinguished from the horizontal synchronizing pulse by being given a length equal to the time required for three lines. This is approximatly 19 times the length of the horizontal synchronizing pulses. The vertical synchronizing pulse is shown in Figure 2-1 (b).

The television standards of the United State specify that the signals modulated on the transmitter carrier must have the character shown in Figure 2-2. This is a voltage waveform of one horizontal line of a typical television signal at the output of the video detector (see Figure 2-5). The time scale is shown in microsecond units and amplitude scale is shown in I.R.E (Institute of Radio Engineer) units. 100 I.R.E unit is defined as the maximum reference white level and 0 I.R.E unit is the level of the backporch and frontporch of the horizontal blanking pulse. Reference black level corresponds to +7.5 I.R.E



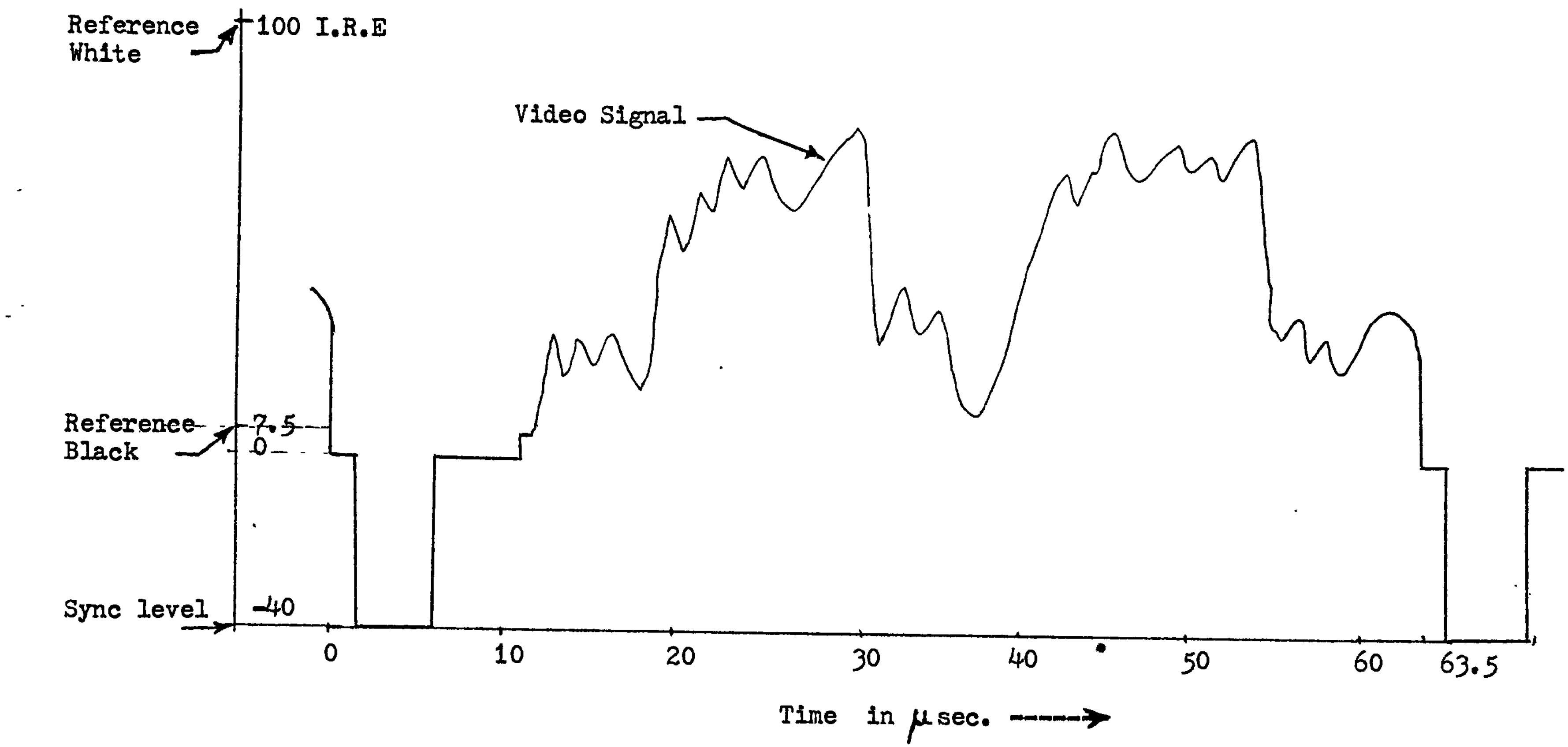
HORIZONTAL BLANKING PULSE (VOLTAGE WAVEFORM)

Figure 2-1 (a).



VERTICAL BLANKING PULSE (VOLTAGE WAVEFORM)

Figure 2-1 (b).



LUMINANCE SIGNAL (MONOCHROME)

Figure 2-2.

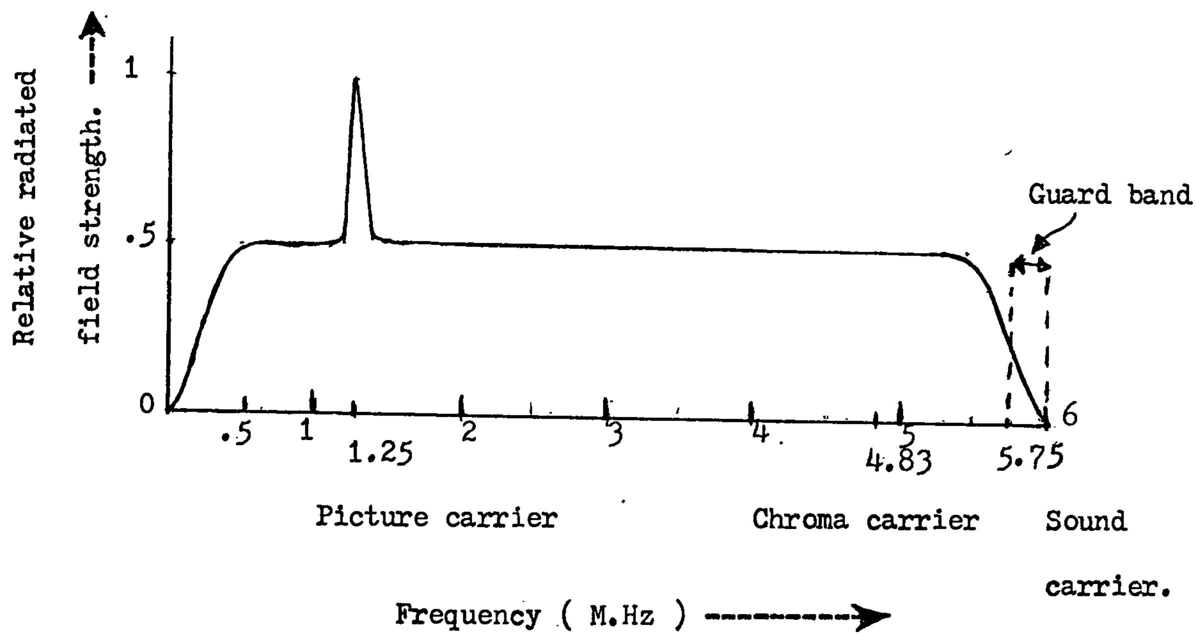
and synchronizing pulse level is at - 40 I.R.E. We observe from this that blanking pulses are transmitted as blacker than black.

Amplitude modulation is used in the transmission of the television video signal. The synchronizing pulse level corresponds to 100 % picture carrier level and reference peak white level corresponds to about 12.5 % of the picture carrier. Peak whites are not allowed to go below 12.5 % of the picture carrier for following two reasons.

(1) To prevent interference in the intercarrier sound system.

(2) To prevent white clipping.

Television stations are assigned channels in the frequency range from 54 to 88 M.Hz, 174 to 216 M.Hz and 470 to 890 M.Hz. Channels are 6 M.Hz wide and are arranged as shown in Figure 2-3.



FREQUENCY RESPONSE OF A CHANNEL

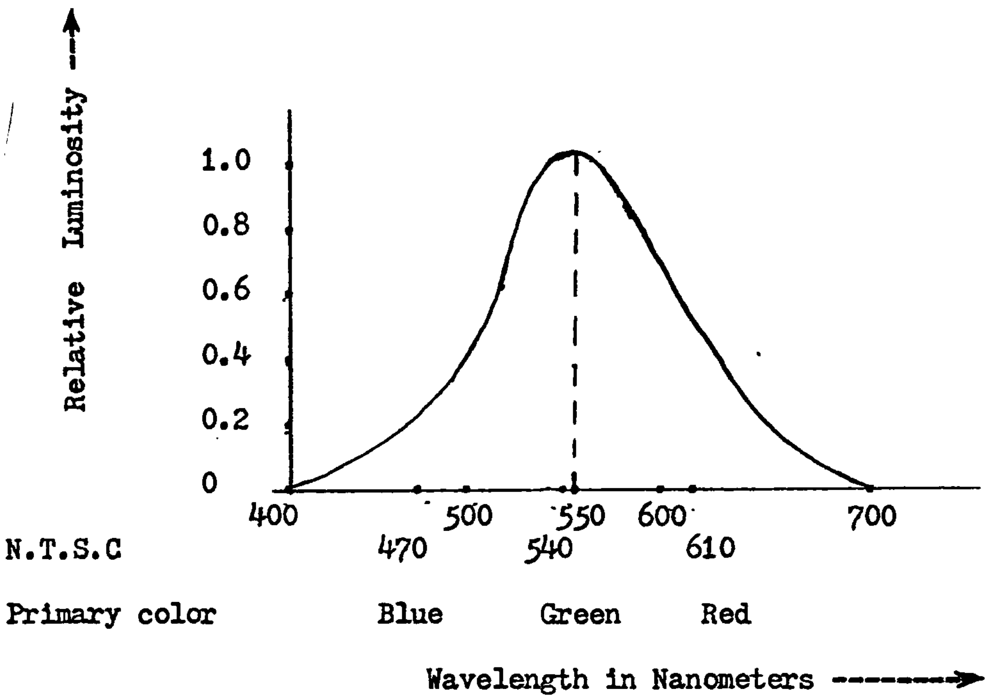
Figure 2-3.

Vestigial sideband transmission is used with the picture carrier at 1.25 M.Hz above the low frequency end of the band. A frequency band slightly over 4.25 M.Hz wide is available for the upper sideband. The sound accompanying the television picture signal is transmitted on the carrier frequency 4.5 M.Hz greater than the picture carrier frequency. Frequency modulation is used for the sound transmission, with a maximum frequency deviation of 25 K.Hz. The color accompanying the television picture signal is transmitted on the carrier frequency 3.58 M.Hz greater than the picture carrier frequency.

Vestigial sideband transmission is used for the color television signal transmission because of its ability to transmit very low frequency signals, including D.C. information. This is important for television signals because most of the video information is in the low frequency signal, and information about the average brightness of the scene is the d.c component of the video signal.

Light is one of the many forms of radiant energy, and the light which is useful to the eye occupies only a small portion of the radiant energy spectrum. Light is made up of radiant energy having wavelengths between 400 and 700 nanometer. When all wavelengths of the light spectrum from 400 to 700 nanometers are presented to the eye in nearly equal proportions white light is seen. This white light is made up of various wavelengths which are representative of different colors, which can be demonstrated by passing white light through a prism. Red colors fall between 620 to 700 nanometers, green colors between 490 to 550 nanometers and blue colors between 400 to 490 nanometers.

An average can be taken of the color response of a number of people, and a standard response can be derived. This standard response is shown in Figure 2-4 and is called the luminosity curve for the standard observer.



LUMINOSITY RESPONSE OF THE EYE

Figure 2-4.

Experiments have shown that a wide range of colors can be matched by combinations of three light sources. The three colors which are used are red, green and blue. Standards for the specification of these colors were adopted by the "Commission International de l'Eclairage" (C.I.E) at a meeting in 1931. These standards provide that the red primary shall correspond to a light of a wavelength of 700 nanometers, green to a wavelength of 546.1 nanometers, and blue to a wavelength of 435.8 nanometers. When primary colors were selected for color television work, it was found that those primaries must of necessity be limited by the color phosphors that were available for the picture tube. Therefore N.T.S.C red has a wavelength of approximatly 610 nanometers, green is approximatly 540 nanometers, and blue is approximatly 470 nanometers.

Each additive primary contributes a certain percentage of the brightness in the white which results from the mixture. Green is the brightest of the three primaries, red is the second brightest, and blue is the dimmest. The eye responds more to green than to any of the other primary colors. With the total brightness of white considered as unity, green contributes 59 % of the total, red 30 % and blue 11 %. Therefore, the luminance signal intensity Ey in terms of the individual color intensities Er, Eg and Eb, is given by Equation 2-1 :

$$Ey = .3\,Er + .59\,Eg + .11\,Eb \qquad (2\text{-}1)$$

The individual intensities, Er, Eg and Eb, are obtained from the three individual tubes in a color camera.

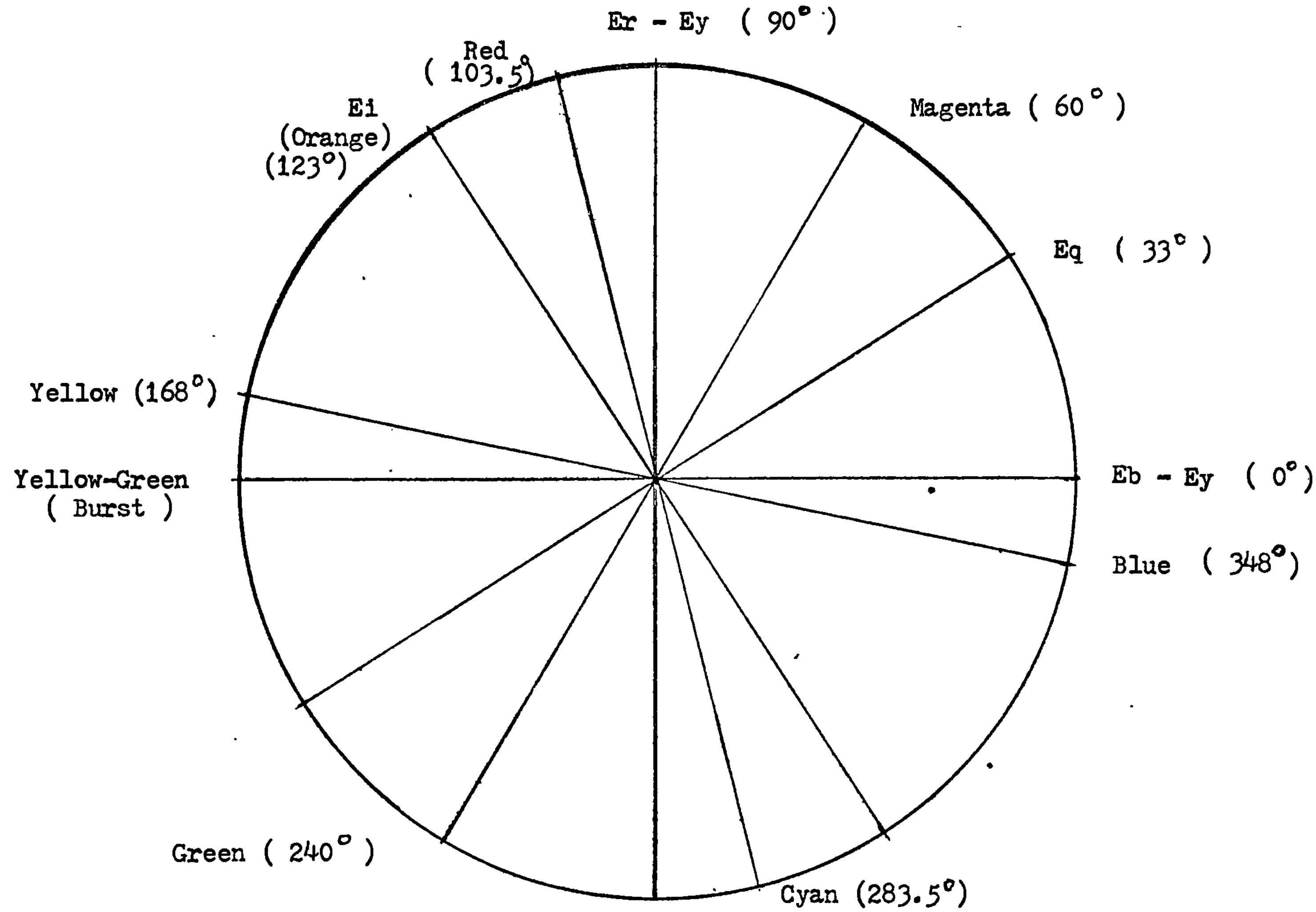
The luminance signal Ey produces a black and white version of the color picture on a monochrome television receiver, and on a color television receiver it provides the brightness information. It is essentially identical to conventional black and white signal and is transmitted as white or shades of gray. The bandwidth of this signal is from d.c to 4.25 M.Hz. This bandwidth limitation is dictated by the television channel bandwidth.

Three primary color signals, red color signal Er, green color signal Eg, and blue color signal Eb are needed to reproduce a color scene at the receiver. Considerable work was done in selecting the three signals for the transmission of the primary color signals. The luminance signal Ey is required for monochrome transmission, and to provide maximum picture detail this signal should utilize full channel bandwidth. Since Ey is a function of Er, Eg and Eb, only two more signals must be transmitted. These signals, called Ei and Eq, are formed by combining Er, Eg and Eb in a manner that is described below.

Colorimetry experiments performed on an average observer indicated that human eye can interpret the fine details in orange and cyan colors only, whereas for coarse detail and large areas of the image it is able to interpret all the colors. Therefore the Ei signal is selected on the orange - cyan axis (see Figure 2-5 (a) known as color circle) for the transmission of fine detail colors. Both sidebands of Ei signal are transmitted for frequencies up to 0.5 M.Hz, and only the lower sideband is transmitted for frequencies from 0.5 to 1.5 M.Hz. The Eq signal in quadrature to Ei signal is limited to 0.5 M.Hz, and both sidebands are transmitted. Shown in the Figure 2-5 (b) is the passband of the color picture signal.

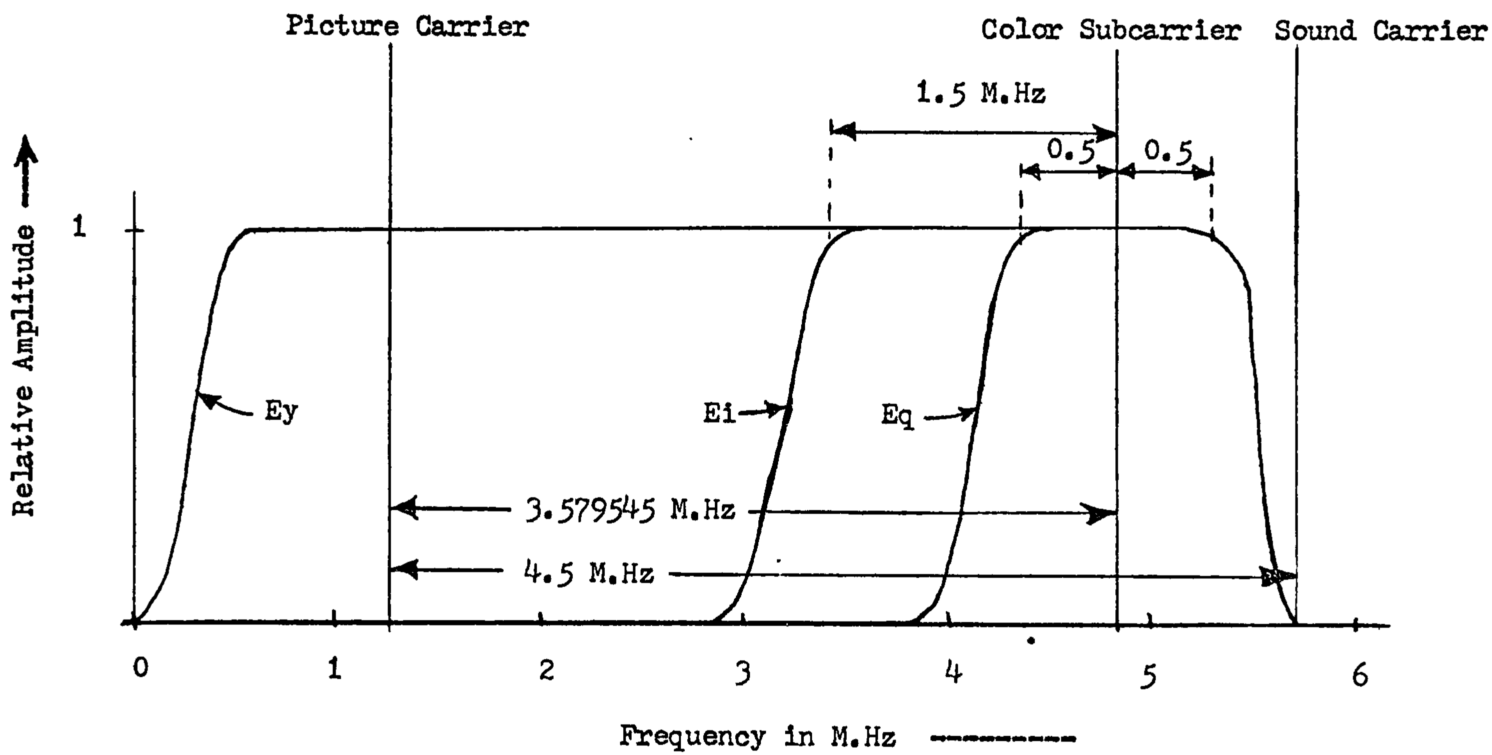
The three color difference signals are formed by subtracting luminance signal Ey from each of the three output voltages of the color camera.

Since $$Ey = .3\,Er + .59\,Eg + .11\,Eb$$



<u>COLOR CIRCLE.</u>

Figure 2-5 (a).



PASSBAND OF THE COLOR PICTURE SIGNAL

Figure 2-5.(b).

Therefore
$$Er - Ey = .7\,Er - .59\,Eg - .11\,Eb \qquad (2\text{-}2)$$
$$Eg - Ey = -.3\,Er + .41\,Eg - .11\,Eb \qquad (2\text{-}3)$$
$$Eb - Ey = -.3\,Er - .59\,Eg + .89\,Eb \qquad (2\text{-}4)$$

The Ei and Eq signals are formed by matrixing Er - Ey and Eb - Ey color difference signals. These two color difference signals are reduced in amplitude in order to prevent over modulation of the video signal. The video signal consists of the luminance signal and the chrominance signal. The amplitude of the luminance signal can not be changed because it must remain compatible with monochrome standards. Therefore the amplitude of the chrominance signal is reduced by reducing the amplitude of the color difference signals. The Er - Ey signal is reduced by a factor of .877 and the Eb - Ey signal is reduced by a factor of .493. At the receiver, the gain of the demodulators, detecting the Er - Ey and Eb - Ey color difference signals, are adjusted to compensate for the reduction at the transmitter.

The signal Ei, leads Er - Ey by 33° and leads Eb - Ey by 123°, therefore E_i signal can be expressed in terms of these two color difference signals as shown by Equation 2-5.

$$\begin{aligned} Ei &= .877\,(Er - Ey)\cos 33^\circ + .493\,(Eb - Ey)\cos 123^\circ \\ &= .74\,(Er - Ey) - .27\,(Eb - Ey) \qquad (2\text{-}5) \end{aligned}$$

The signal Eq, lags Er - Ey by 57° and leads Eb - Ey by 33°. Therefore an expression for Eq in terms of these two color difference signals is given by Equation 2-6.

$$Eq = .877\,(Er - Ey)\cos 57^\circ + .493\,(Eb - Ey)\cos 33^\circ$$

$$Eq = .48\ (Er - Ey) + .41\ (Eb - Ey) \qquad (2\text{-}6)$$

The Ei and Eq color signals are formed from the two color difference signals according to Equations (2-5) and (2-6). The Ei signal modulates a subcarrier, Cos (wt + 33°), whereas the Eq signal modulates a subcarrier, Sin (wt + 33°). The phase reference wt is the phase of the color burst plus 180 degrees. The outputs of the modulators are combined to form the chrominance signal. This signal is fed to an adder section where it combines with the luminance signal. The output of the adder section is the video signal Em and is given by Equation 2-7.

$$Em = Ey + Eq\ \mathrm{Sin}\ (wt + 33^\circ) + Ei\ \mathrm{Cos}\ (wt + 33^\circ) \qquad (2\text{-}7)$$

The sync, blanking, and color burst signals are added to the above signal, and then the composite video signal vestigial sideband modulates the picture carrier. The chrominance signal Vc is given by Equation 2-8.

$$Vc = Eq\ \mathrm{Sin}\ (wt + 33^\circ) + Ei\ \mathrm{Cos}\ (wt + 33^\circ) \qquad (2\text{-}8)$$

For a white signal the three color outputs (Er, Eg, Eb) of the color camera are each equal to unity. Therefore from equation (2-1), the luminance signal Ey for white light is also unity. This relationship is given by Equation (2-9).

For white light :

$$Er = Eg = Eb = Ey = 1 \qquad (2\text{-}9)$$

Therefore for white light all the three color difference signals given by equations (2-2), (2-3) and (2-4) will be equal to zero, this means that signals Ei and Eq will also be equal to zero. The video signal Em for black and white signal is then equal to the luminance signal Ey.

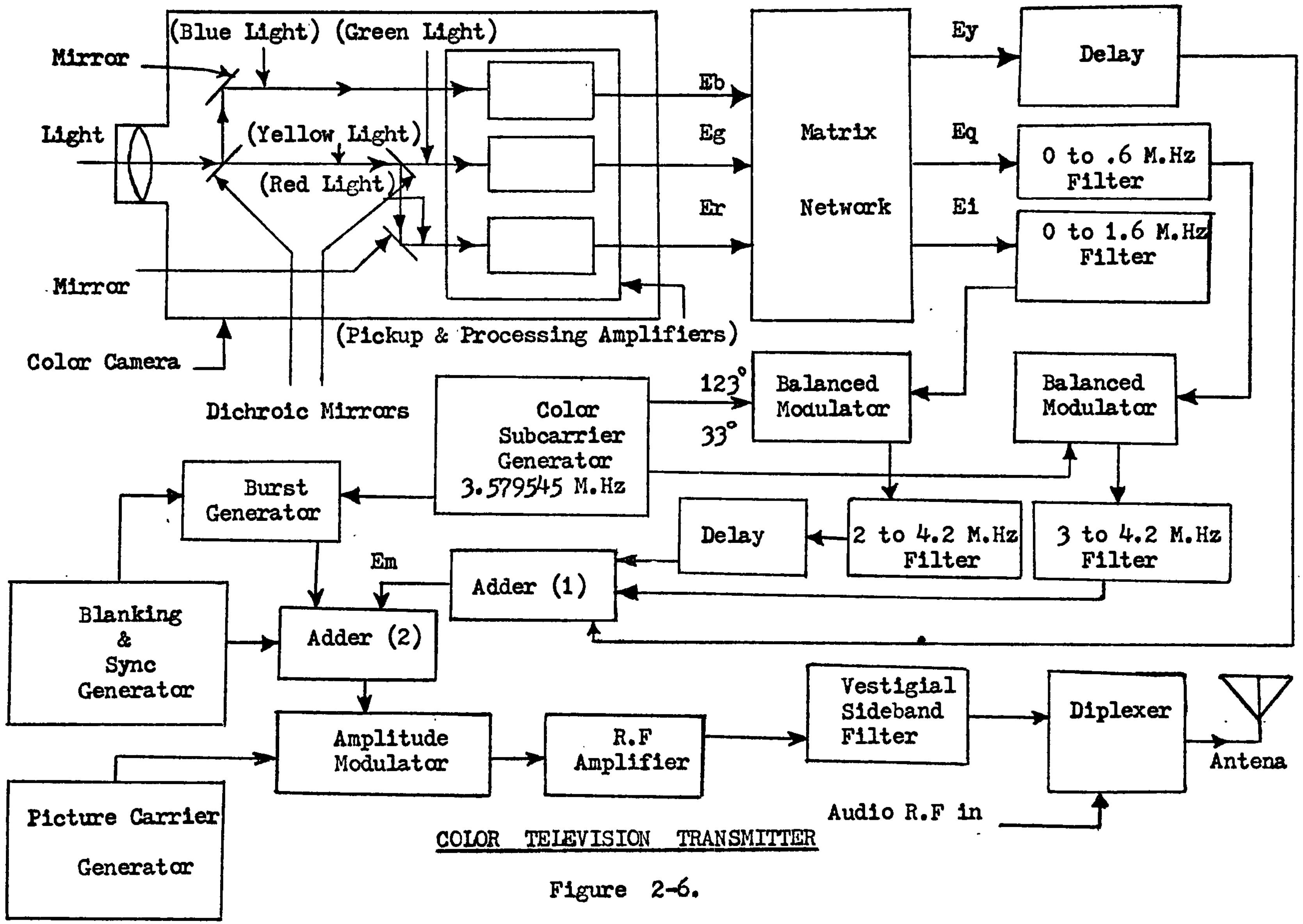
The chrominance signal Vc is the combined hue and saturation information of the colored object. Hue, also called tint, is generally the most noticable quality of light perceived by the eye. Hue is the characteristic of visible light energy that identifies the wavelength of radiant light and is usually interpreted by the normal eye as red, blue, yellow, etc. Saturation can be described as the vividness of a color in terms of pale, pastel, deep, etc. Saturation is a measure of how much the particular color differs from gray or white. The hue and saturation are given by the phase and amplitude, respectively, of the chrominance signal. From Equation (2-8),

$$\phi = \mathrm{Tan}^{-1} \frac{E_i}{E_q} \qquad (2\text{-}10)$$

$$|Vc| = \sqrt{Ei^2 + Eq^2} \qquad (2\text{-}11)$$

2-2 Color Television Transmitter :

The color television transmitter uses red, green and blue as primary colors. At the camera each color in the scene is optically reduced to the three primary colors through the use of color filters. The amount of light passing through each filter into the three camera tubes produces picture signals representative of the amounts of the three primary colors present in colored objects being scanned by the camera. White light produces equal amounts of red, blue and green video



COLOR TELEVISION TRANSMITTER

Figure 2-6.

signals. The luminance signal consists of fixed percentages of red, green and blue signals, as shown by Equation 2-1.

The system diagram of a color television transmitter is shown in Figure 2-6. The color camera divides the light of the image from the scene into three primary color signals. The processing amplifiers are adjusted so that for white light the camera provides unit red, blue and green signals; that is, it satisfies the Equation 2-9. The matrix network provides the luminance signal Ey, formed according to Equation 2-1, and two chrominance signals Ei and Eq, formed according to Equations 2-12 and 2-13 given below. These are obtained by solving Equations 2-2, 2-4, 2-5 and 2-6 for Ei and Eq.

$$Ei = .60\ Er - .28\ Eg - .32\ Eb \qquad (2\text{-}12)$$

$$Eq = .21\ Er - .52\ Eg + .31\ Eb \qquad (2\text{-}13)$$

The three signals Ey, Ei and Eq have unequal bandwidth, as shown by Figure 2-5. This means that time delay networks must be inserted in the Y and I channels, as shown by Figure 2-6, so that all three channels are transmitted in time coincidence.

The chrominance signals Ei and Eq are passed through a low-pass filter to remove high frequency video signals. The Eq signal amplitude modulates the color subcarrier Sin (wt + 33°), and the Ei signal amplitude modulates the color subcarrier Cos (wt + 33°). Balanced modulators are used so that in absence of Ei and Eq signals the modulator output reduces to zero. The amplitude modulated chrominance signals pass through the passband filter which have the frequency responses illustrated in Figure 2-5. The three signals Ey, Ei and Eq are added to form the video signal Em.

The burst signal, which is eight to ten cycles of color subcarrier signal at 57° leading phase to Cos ($wt + 33^{\circ}$) signal, is generated and added to the video signal during the backporch interval. The horizontal and vertical blanking and synchronization pulses are added to the video signal. The composite video signal thus formed amplitude modulates the picture carrier. The output of the modulator is amplified by a R.F amplifier and its output, after passed through a vestigial sideband filter, is added with the audio R.F in a Diplexer. Thereafter it is radiated by an antena for transmission.

2-3 Synchronous Modulation And Demodulation :

Synchronous quadrature modulation is employed in order to modulate two independent signals on a single subcarrier. The Ei color signal amplitude modulates the 3.58 M.Hz color subcarrier signal. This color subcarrier signal lags the burst (the phase reference signal transmitted during horizontal blanking) by 57°. This amplitude modulated color subcarrier signal is called the Vi signal, and is one component of the chrominance signal. The Eq, color signal amplitude modulates the other 3.58 M.Hz color subcarrier signal, which lags the burst by 147°. This amplitude modulated color subcarrier signal is called the Vq signal and is the second component of the chrominance signal. The two amplitude modulated color subcarrier signals are added to form the chrominance signal Vc. The three signals Vi, Vq and Vc are given Equations 2-14, 2-15 and 2-16.

$$Vi = Ei \operatorname{Cos}(wt + 33^\circ) \qquad (2\text{-}14)$$

$$Vq = Eq \operatorname{Sin}(wt + 33^\circ) \qquad (2\text{-}15)$$

$$Vc = Eq \operatorname{Sin}(wt + 33^\circ) + Ei \operatorname{Cos}(wt + 33^\circ)$$
$$= \sqrt{(Ei)^2 + (Eq)^2} \quad \operatorname{Sin}(wt + 33^\circ + \phi) \qquad (2\text{-}16)$$

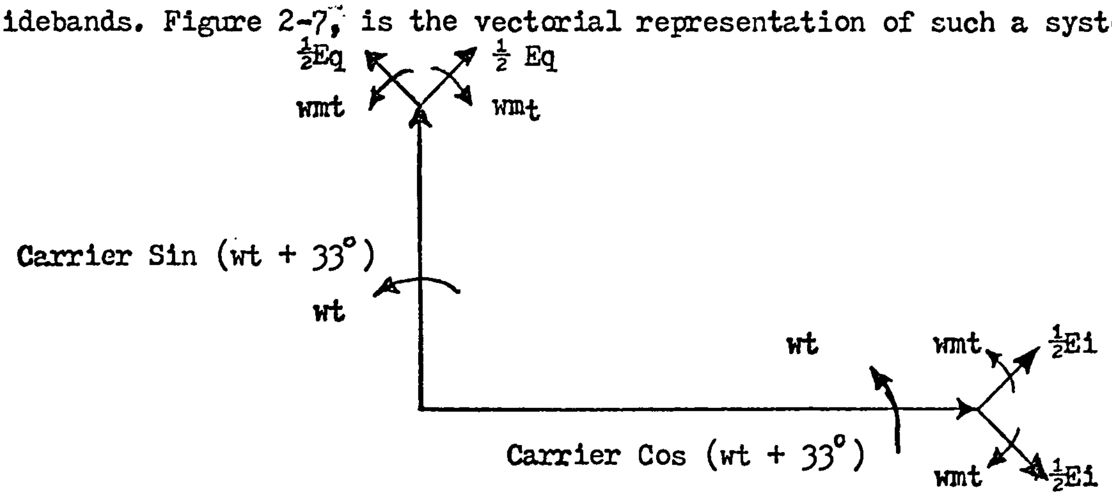
Where
$$\phi = \operatorname{Tan}^{-1} \frac{E_i}{E_q}$$

Hence the saturation of the colored object is given by :

$$|Vc| = \sqrt{(Ei)^2 + (Eq)^2}$$

and the hue of the colored object is given by $(33^\circ \times \frac{\pi}{180} + \phi)$ in radians.

Quadrature modulation is a combination of amplitude and phase modulation. The phase and amplitude factors, however, are not directly related to the modulating signals. Since there are two a.m systems in quadrature, each therefore, may have its own carrier and symmetrical sets of sidebands. Figure 2-7, is the vectorial representation of such a system.



VECTORIAL REPRESENTATION OF QUADRATURE MODULATION.

Figure 2-7

The frequency wm is the angular rate at which the color signal is changing, and that is a function of the rate of change of color in the scene being scanned. The reason for selecting Ei and Eq signal to form the chrominance signal Vc was discussed earlier, and it was shown that eye can resolve more fine details in the orange (fleshtone) or cyan colors than any other colors. The color represented by Ei lies on the orange color axis of color circle of Figure 2-4, and the color represented by Ei is on the cyan color axis. Threrefore Ei has been given larger bandwidth than Eq.

At the receiver Vc can be amplified and passed through a passband filter, 2 to 4.2 M.Hz, and then demodulated to recover the Ei signal. The amplified Vc signal can be passed through another passband filter, 3 to 4.2 M.Hz, and then demodulated to recover the Eq signal. Because the bandwidths of the Ei and Eq signals are different, the Ei signal must be delayed in a delay network.

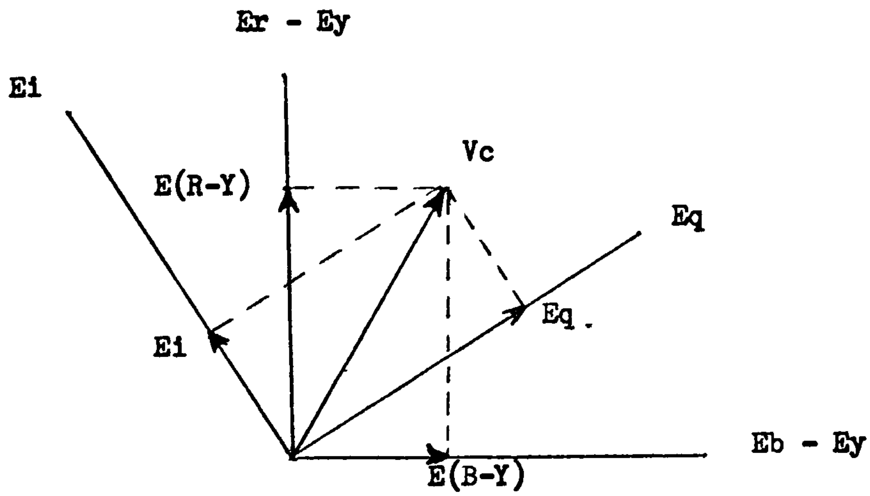
A receiver can be simplified by not using the transmitted high frequency information in the orange-cyan colors. In such a simplified system the filter bandwidths can be the same. Therefore they will have equal delay, and the delay network can be eliminated.

Equation 2-16, can be rewritten to show for color difference signals.

$$Vc = Eq \text{ Sin } (wt + 33^{\circ}) + Ei \text{ Cos } (wt + 33^{\circ}) \quad (2\text{-}16)$$

$$Vc = (Eb - Ey) \text{ Sin } wt + (Er - Ey) \text{ Cos } wt \quad (2\text{-}17)$$

The relationship of the color difference signals, the chrominance signal Vc and the Ei and Eq signals is shown by Figure 2-8.



RELATIONSHIP OF Vc WITH COLOR DIFFERENCE SIGNALS, Ei AND Eq SIGNALS

Figure 2-8.

In the simplified demodulation system, both demodulators are operated at a phase such as to derive color difference signals directly. The bandwidth of the detected color difference signals, (Er - Ey) and (Eb - Ey), is approximatly 500 K.Hz. The chrominance signal Vc at the receiver can be synchronously detected by using local signals equal to V Sin wt and V Cos wt. The output of the (R-Y) demodulator is given below.

Output of the (R-Y) demodulator;

$$= Vc.\ V \cos wt$$

$$= (Er - Ey) \cos wt + (Eb - Ey) \sin wt\ .\ V \cos wt$$

$$= \tfrac{1}{2} V\ (Er - Ey) - \tfrac{1}{2} V\ (Er - Ey) \cos 2wt +$$

$$\tfrac{1}{2} V\ (Er - Ey) \sin 2wt.$$

This output after a low-pass filter is given by Equation 2-18, and is called the E(R-Y) signal.

$$E(R-Y) = \tfrac{1}{2} V (Er - Ey) \tag{2-18}$$

The E(B-Y) signal is obtained by demodulating the chrominance signal Vc with V Sin wt and passing this output through a low-pass filter. The E(B-Y) signal is given by Equation 2-19.

$$E(B-Y) = \tfrac{1}{2} V (Eb - Ey) \tag{2-19}$$

Therefore the E(R-Y) and E(B-Y) signals at the receiver are proportional to the transmitted color difference signals. Third color difference signal E(G-Y) is obtained by matrixing E(R-Y) and E(B-Y) color difference signals according to Equation 2-21. Equation 2-21 can be derived as follows.

$$Ey = .3\ Er + .59\ Eg + .11\ Eb \tag{2-1}$$

Therefore, $Eg = 1.7\ Ey - .51\ Er - .19\ Eb$

and $$(Eg - Ey) = -.51\ (Er - Ey) - .19\ (Eb - Ey) \tag{2-20}$$

At the transmitter the (Eg - Ey) color difference signal is related to the other two color difference signals by Equation 2-20. Therefore at the receiver the E(G-Y) color difference signal should be given by Equation 2-21.

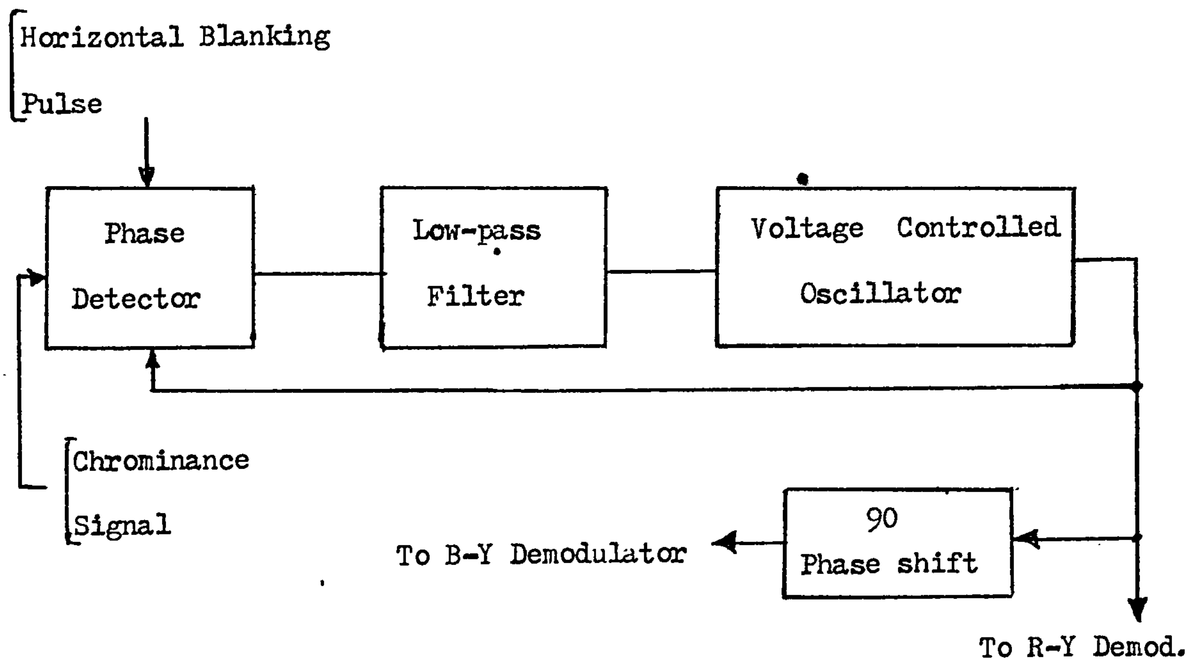
$$\begin{aligned} E(G-Y) &= -.51\ E(R-Y) - .19\ E(B-Y) \qquad (2\text{-}21) \\ &= -.51 x \tfrac{1}{2} x V x (Er - Ey) - .19 x \tfrac{1}{2} x V x (Eb - Ey) \\ &= \tfrac{1}{2} x V \quad -.51\ (Er - Ey) - .19\ (Eb - Ey) \\ &= \tfrac{1}{2} x\ V x\ (Eg - Ey) \end{aligned}$$

Therefore the E(G-Y) color difference signal at the receiver obtained by matrixing the other two color difference signals is proportional to the (Eg - Ey) transmitted color difference signal. The luminance signal equal to $\frac{1}{2}$VxEy is added to the three color difference signals in order to recover the three primary color signals at the receiver.

2-4 The Burst Signal :

The burst signal, as the name implies, is a burst of eight to ten cycles of 3.579545 M.Hz color subcarrier signal, transmitted during the horizontal blanking interval as shown by Figure 2-1(a). The burst is transmitted for the reference of phase and amplitude of the chrominance signal. It has been shown that in order to detect two color difference signals from the received chrominance signal, two locally generated signals, V Sin wt and V Cos wt, are needed. For accurate demodulation of the received chrominance signal, the proper phase relationship between the chrominance signal and the two locally generated signals is very important. The receiver must generate V Sin wt and V Cos wt because the color subcarrier is not transmitted.

The subcarrier can be generated by using a voltage controlled oscillator. A voltage controlled oscillator (V.C.O), is a C.W oscillator whose phase and therefore frequency can be controlled by a D.C correction voltage. This D.C correction voltage is an output of a phase detector, where the oscillator signal is phase compared with the burst signal. This is achieved by gating on the phase detector only during the horizontal blanking period. Therefore the output of the phase detector, which has a low-pass filter, provides a correction voltage which is proportional to the error in the oscillator signal phase. The system described above is shown by Figure 2-9.



PHASE LOCK VOLTAGE CONTROLLED OSCILLATOR

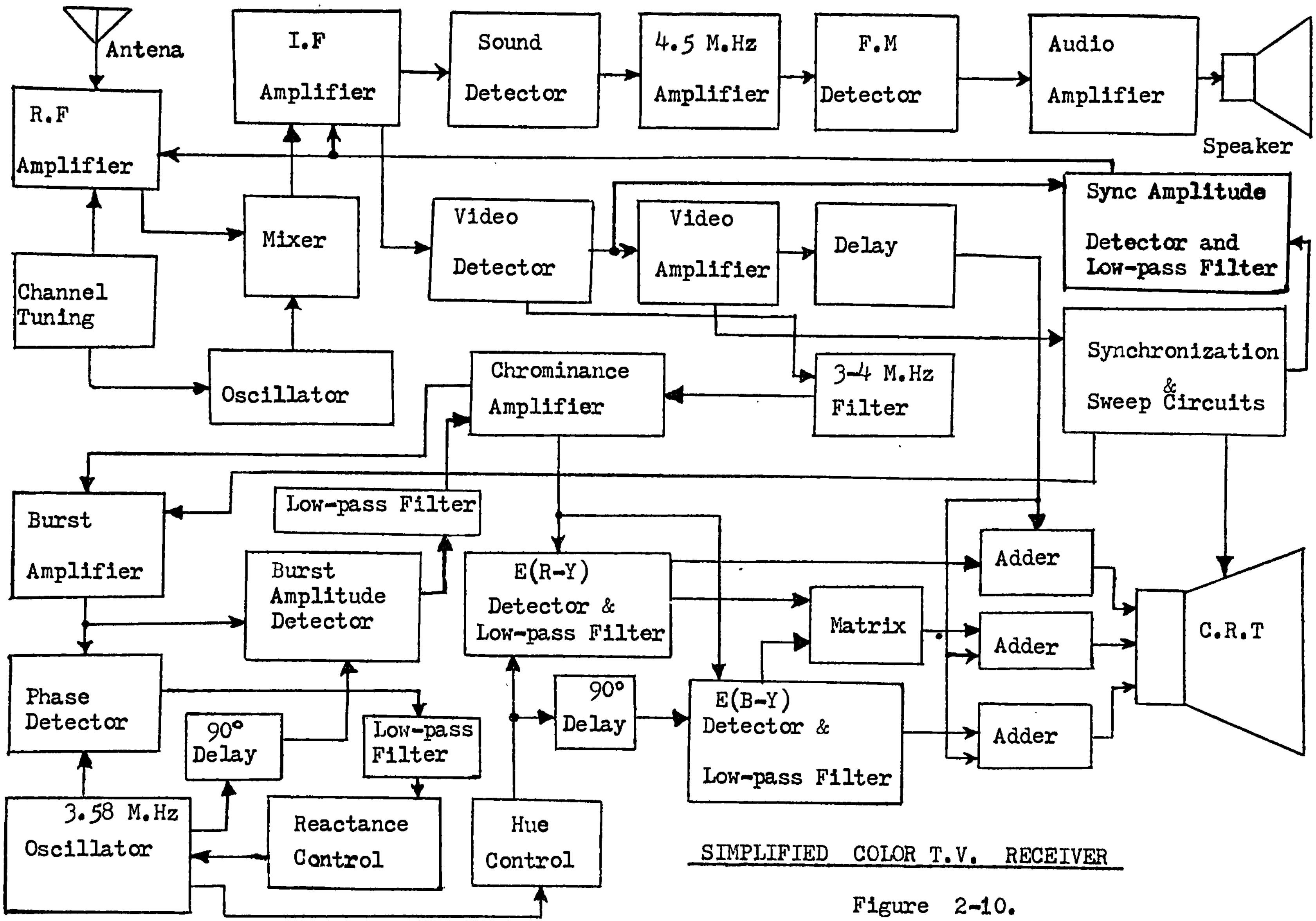
Figure 2-9

The output of the voltage controlled oscillator lags the burst phase by 90°, when there is no static phase error. The reference subcarrier signal is used for synchronous detection of the chrominance signal to obtain the color difference signals. The burst has been used as a phase reference for the chrominance signal. This has been done because, at the transmitter, burst phase is related to the chrominance signal. Therefore, the burst is also often refered to as the phase reference signal.

The burst, besides providing the phase reference for the chrominance signal, also provides the amplitude reference for the chrominance signal. Refering to Figure 2-1 (a), it is observed that according to N.T.S.C standards, peak white is 100 I.R.E units, sync amplitude is 40 I.R.E units and Burst amplitude is 40 I.R.E units. Therefore, burst amplitude is related to chrominance amplitude and also to luminance amplitude.

At the receiver, the luminance signal amplitude is maintained constant by keeping the sync amplitude constant; see Figure 2-10 (The simplified color television receiver). This is done by detecting the sync amplitude and low-pass filtering it to obtain a signal to control the gain of the I.F and R.F amplifiers. A similar technique is used for the chrominance signal. In this case the burst amplitude is detected and filtered to obtain the gain control voltage for the chrominance amplifier. The chrominance signal amplifier is gain controlled to maintain the amplitude of the burst and chrominance signal at a constant voltage. Since the gain of the I.F and R.F amplifiers is being controlled to maintain the sync and luminance signals at a constant amplitudes, the burst and chrominance signal amplitude must also be constant because the burst amplitude is related to sync amplitude. There are two main reasons for using a seprate gain control for the chrominance signal.

(1) The I.F and R.F amplifiers frequency response changes with gain control and channel tuning, since the chrominance signal shares the narrow high frequency band of the total luminance signal bandwidth,



SIMPLIFIED COLOR T.V. RECEIVER

Figure 2-10.

such a frequency responce change will effect the chrominance signal amplitude in relation to the low frequency luminance signal.

(2) The signal transmission system between the transmitter and the receiver may also introduce a high frequency loss of the video signal resulting in the reduction of the chrominance signal amplitude in relation to the luminance signal. This type of distortion is known as " Video Path Distortion ", and will be discussed under subheading " Signal Distortion ".

The F.C.C specification with tolerances, giving the amplitude relationships of the various signals, is given by Table 2-1.

Table 2-1

Relationship			Maximum	Minimum
Chrominance	VS	Luminance	1.2	0.8
Luminance	VS	Sync	3.0	2.09
Sync	VS	Burst	1.1	0.90

2-5 Signal Distortion :

Signal distortion in a television video signal may be due to two following reasons.

(1) Video Path Distortion.

This type of distortion is caused by elements in the distribution system, and in the transmission path from network studio to local television studio. For the chrominance signal this may result in loss of the chrominance and the burst amplitude in relation to the luminance signal. We will call this " Chrominance amplitude distortion."

(2) Signal Source Distortion.

This type of distortions occurs when the signal is not correctly formed initially. This type of distortion arises from the generating sources, such as camera, encoder, video tape recorder, etc, at the television studio originating the program. For the chrominance signal this may result in two kind of distortions: (i) Chrominance amplitude to burst amplitude ratio may not be correct, thus the receiver does not have the true chrominance amplitude reference. This will be called "Chrominance amplitude to burst amplitude ratio distortion." (ii) Chrominance phase may not be correctly related to burst phase, thus the receiver does not have the true chrominance phase reference. This will be called "Chrominance phase to burst phase reference distortion."

References :

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By B.D.Loughlin, I.E.E.E. Intercon 1973 Convention record 39/1.

(3) Electronic and Radio Engineering.

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(4) Television System Measurements.

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Book series No : 062 - 0955 - 00.

III. AUTOMATIC COLOR SATURATION CORRECTION

3-1 Video Path Distortion And Its Correction :

The various sources and causes of signal distortion and their effects on the chrominance signal amplitude have been discussed. Video path distortion, which is very common in television signal transmission, causes the chrominance amplitude and burst amplitude to vary in relation to the low frequency luminance signal. However this type of distortion does not introduce an error in the ratio of the chrominance amplitude to the burst amplitude. Therefore, the burst can be treated as a true chrominance amplitude reference. By keeping the burst amplitude constant we can correct for video path distortion.

This entire chapter will deal with the more difficult problem of the color saturation error that is due to signal source distortion. This type of error is caused by the lack of a true amplitude reference in the transmitted signal.

3-2 Signal Source Distortion And Its Correction :

The signal source distortion that is related to color saturation is one of the most objectionable errors found in the television video signal. This distortion is due to the broad N.T.S.C system tolerance, as accepted by F.C.C, for the burst to chrominance amplitude relationship. These tolerances are listed in Table 2-1. Some television transmitters also introduce signal source distortion because of nonlinearities in their video amplifiers. In particular, nonlinearities at the higher power levels can result in the sync and burst signals being modified with respect to the luminance and chrominance signals. This produces nonuniformity in the luminance and color reproduction between various transmitters. Any attempt to correct this distortion at the receiver will result in more distortion because the burst signal does not provide an accurate amplitude reference for the chrominance signal. A better system to correct signal source distortion for color saturation would be based on the amplitude of the chrominance signal itself.

The chrominance signal carries the color information in a scene, and, therefore, it is random in nature. The types of color scenes that can exist can be put into two general catagories, namely (1) Saturated color scene (2) Unsaturated color scene.

(1) Saturated Color Scene :

The scene having saturated color or colors. This can be of two different types.

(a) Highly Saturated Color Scene.

This is a scene having more than 50 % of the television frame consisting of saturated colored objects. This could be distributed as lots of small area objects or as a one big object in a scene.

(b) Lightly Saturated Color Scene.

This is a scene having less than 50 % of the television frame consisting of saturated colored objects. This could be distributed as lots of small area objects or as a one big object in a scene.

(2) Unsaturated Color Scene.

The scene having no object with saturated colors. These could be of three different types.

(a) Highly Unsaturated Color Scene.

This is a scene in which the maximum chrominance amplitude is equal or less than half of the burst amplitude.

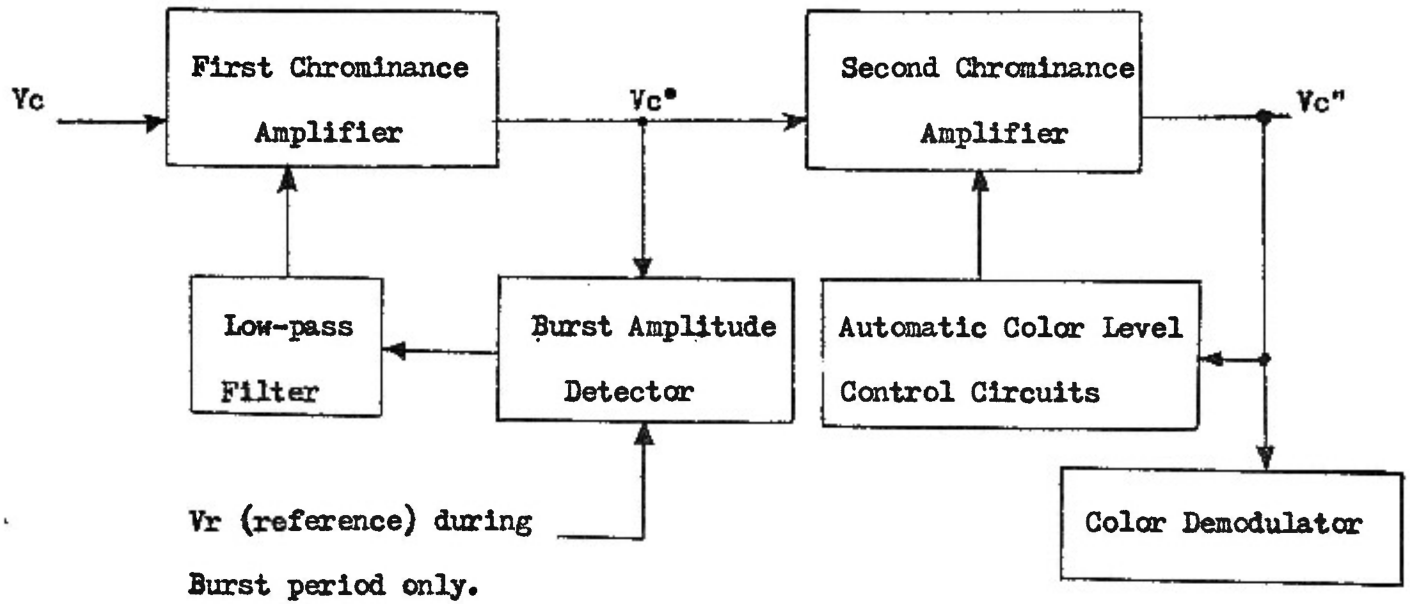
(b) Average Unsaturated Color Scene.

This is a scene in which the maximum chrominance amplitude is more than half the burst amplitude but less than the burst amplitude.

(c) Lightly Unsaturated Color scene.

This is a scene in which the maximum chrominance amplitude is more than the burst amplitude but less than the saturated chrominance level.

The chrominance signal has been defined for various types of scenes so that it can be used to evaluate any automatic color level control system. There are several known automatic color level control circuits. Figure 3-1 illustrates a basic chrominance amplifier system of a color television receiver employing some automatic color level control. Automatic color level control is achieved by adjusting the gain of the second chrominance amplifier. This provides a constant chrominance level to the color demodulator. The chrominance signal at the input to the demodulator is applied to the automatic color level control circuit, which process it and provides a d.c voltage to control the gain of the second chrominance amplifier. The automatic color level control circuit forms a closed loop negative feedback system for the second chrominance amplifier.



Vc = Received chrominance Signal.

Vc' = Video path distortion corrected chrominance signal.

Vc" = Signal source distortion improved chrominance signal.

<u>CHROMINANCE AMPLIFIER SYSTEM FOR CORRECTING SIGNAL DISTORTION</u>

Figure 3-1.

The following are the two most common automatic color level control techniques used in present day color television receivers.

(1) Average Color Level Control.

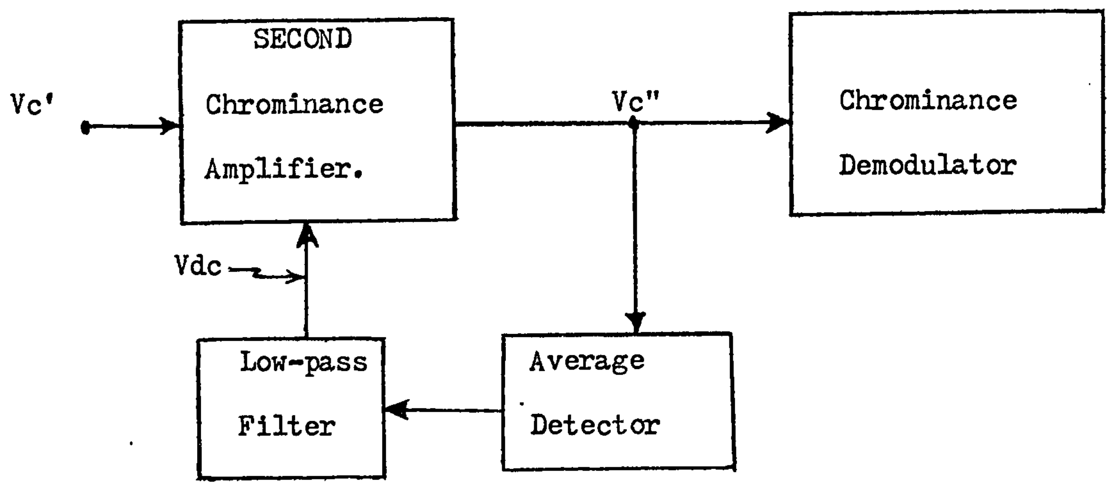
(2) Peak Color Level Control.

The maintainence of the average saturation or peak saturation of the chrominance signal at a given reference level will result in many scenes not being produced as they originated at the transmitter. For example, a scene with a low saturated colored object should not have the same chrominance amplitude as a scene with a high saturated color object. The objective then is to reproduce the scenes at a pleasing color saturation most of the time and accept some errors for some certain kinds of scenes.

Average color level control is a very simple system but has many disadvantages which we will show next. Peak color level control is more accurate but also more complex. Peak color level control will be discussed in detail under subheading 3-4, peak color level control.

3-3 Average Color Level Control :

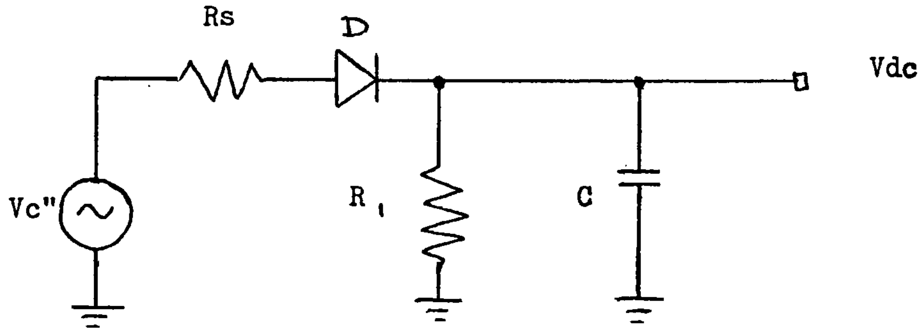
The average color level control system maintains the average value of chrominance level constant at the input of the demodulator. The color level control system is illustrated in Figure 3-2. The input Vc' to the second chrominance amplifier is the chrominance signal which has previously been corrected for video path distortion. The output signal from this amplifier is applied to the chrominance demodulator and the same signal is also applied to the average detector. The output of this detector is applied to the second chrominance amplifier through a low-pass filter to control its gain and thereby maintain a constant average value of chrominance signal level at the input to the chrominance demodulator. Therefore, the average detector and the low-pass filter form a closed loop feedback system for the second chrominance amplifier.



AUTOMATIC COLOR CONTROL SYSTEM USING AVERAGE DETECTOR

Figure 3-2.

The average detector detects the chrominance signal at the frame rate, and therefore the output of this detector represents the average chrominance content of that particular scene. Since the scene is formed in one frame, the charging time constant of the detector should be greater than one frame of the television signal. Figure 3-3. is an equivalent circuit diagram of the average detector and low-pass filter.



EQUIVALENT CIRCUIT OF AN AVERAGE DETECTOR AND LOW-PASS FILTER

Figure 3-3.

The frequency of a television frame is 30 Hz. Assume that $Rs \ll R_1$ and that the resistance of the reverse biased diode is much greater than R_1. Therefore the charging time constant of the above circuit is given by Equation 3-1.

$$Tc \cong C\ Rs \qquad (3\text{-}1)$$
$$\geq \frac{1}{30}\ \text{ms}$$
$$\geq 33.2\ \text{ms}$$

Discharge time constant of the above circuit is given by Equation 3-2.

$$Td \cong C\ R_1 \qquad (3\text{-}2)$$
$$\geq 10 \times \frac{1}{30}\ \text{ms}$$
$$\geq 332\ \text{ms}$$

A large discharge time constant of one second is selected to provide a ripple free correction voltage Vdc, to the second chrominance amplifier.

Performance Of Average Color Level Control.

The objective of the average color level control, as the name implies, is to maintain the average chrominance signal level at the input of the chrominance demodulators. The merit of the system will be determined by its ability to handle various scenes. If a correct signal is being received, the gain of the second chrominance amplifier should remain constant and should not change with changes in the scene. This implies that the correction voltage Vdc applied to the second chrominance amplifier should remain unchanged.

Let us examine the system's control voltage for various color scenes. Let the average color scene be defined as a color scene which consists of saturated colors for half frame. Let the average color level control system provide the d.c voltage equal to Vdc for an average color scene to the second chrominance amplifier. Let the error in the correction voltage, due to change of the color scene from the defined average color scene, be ΔVdc.

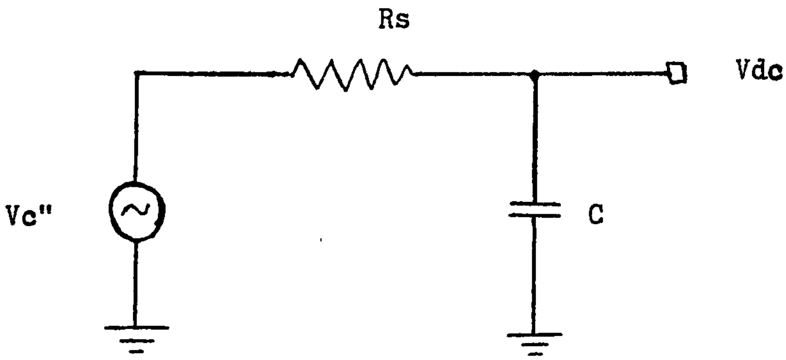
Table 3-1

Type of color scene	Correction Voltage
Highly saturated color scene	Vdc + ΔVdc
Lightly saturated color scene	Vdc - ΔVdc
Highly unsaturated color scene	Vdc - ΔVdc
Average unsaturated color scene	Vdc $\pm$ ΔVdc
Lightly unsaturated color scene	Vdc $\pm$ ΔVdc

The above Table 3-1, indicates that even if the signal at the input to the demodulator is correct, the average color level control system, by providing different correction voltages for different type of color scenes. will cause the chrominance signal at the input to the demodulator to change with the scene. Thus, it will become a cause of chrominance signal distortion at the receiver. However, if the chrominance signal received at the receiver has signal source distortion, then for a given scene, a change in chrominance signal amplitude will cause the correction voltage to change in the direction to adjust the gain of the second chrominance amplifier, and will compensate this change in chrominance amplitude. Because of its poor performance in handling various types of color scenes, this color control system is not satisfactory.

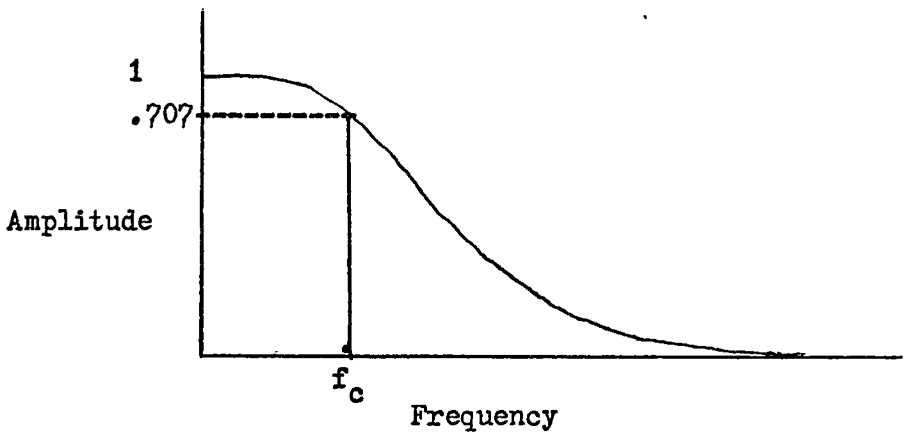
Noise Bandwidth Of Average Detector.

The average color level control system employs an average detector to detect the average chrominance content of a scene, and, therefore, its charging time constant is large. High frequency noise will integrate, and its contribution on the correction voltage will be very little. The noise bandwidth of the average detector and low-pass filter is inversely proportional to the charging time constant. During charging the forward impedance of the diode is very small compared to the source impedance Rs, and, therefore, it can be ignored. Also, since Rs is much smaller than R_1, R_1 could be ignored. An equivalent circuit of the average detector and low-pass filter for charging condition is shown by Figure 3-4, and the frequency response of this circuit is shown by Figure 3-5.



EQUIVALENT CIRCUIT OF AVERAGE DETECTOR & LOW-PASS FILTER FOR CHARGING-CONDITION.

Figure 3-4.



FREQUENCY RESPONSE OF AN AVERAGE DETECTOR WITH LOW-PASS FILTER

Figure 3-5.

$$f_c = \frac{1}{2\,\pi\,Tc}$$

$$\cong \left[2\pi \times 33.2 \times 10\right]^{-1} \cong 4.75 \text{ Hz}$$

Therefore the noise bandwidth of this system is less than 10 Hz.

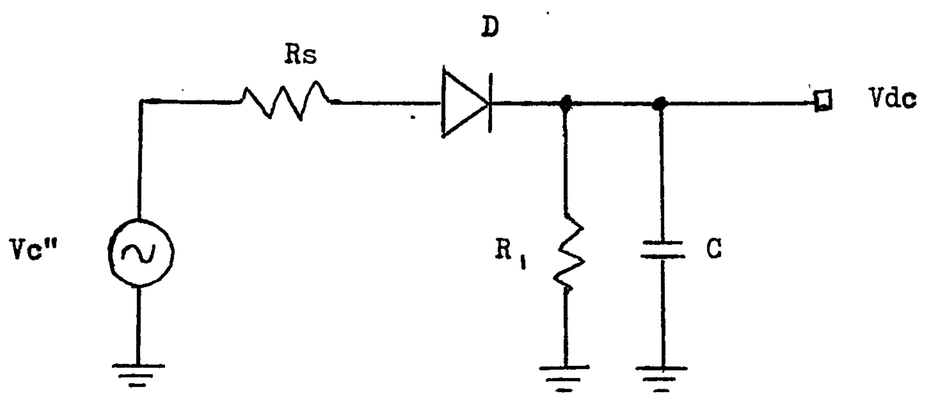
3-4 Peak Color Level Control :

The peak color level control system maintains the peak chrominance level at the input to the demodulator at a constant level. A simple form of the peak color level control system is similar to the average color level control system. The difference is that the average detector is replaced by a peak detector. Therefore the correction voltage Vdc at the output of the low-pass filter is proportional to the peak amplitude of the chrominance signal in a given field. This system is based on the assumption that every scene has some saturated color object. If this is true, then by maintaining the amplitude of the saturated color object at a constant level, the colors of all other objects in the scene will be maintained at their proper levels.

Peak Detector.

The peak detector detects the amplitude of the highest chrominance peak at the frame rate. The correction voltage thus obtained is applied to the second chrominance amplifier to control its gain and keep the peak value of the chrominance output Vc" at a preselected constant level. Let the smallest saturated color object to be measured by the peak detector be a rectangle whose width is equal to 2 % of the screen width and its height is equal to 2 % of the screen height. The trace period of one horizontal line is 52.5 μsecond, therefore screen width in time domain is 52.5 μsecond. There are 490 active lines per frame, therefore height of the screen in time domain is 25.6 msec. (490 x 52.5 μsec). The rectangular saturated color object, in time domain, has a width equal to 1.05 μsec (.02 x 52.5 μsec) and a height equal to 515 μsec (.02 x 25.6 msec). Because the trace period of a horizontal line is 52.5 μsec, the height of the rectangular saturated color object is equal to ten lines. Therefore, in order to provide a correction voltage Vdc representing the chrominance peak of this object, the charging time constant of the peak detector must be at least equal to 10.5 μsec (1.05 μsec x 10 lines).

Noise Bandwidth Of Peak Detector.



EQUIVALENT CIRCUIT OF THE PEAK DETECTOR.

Figure 3-6.

Figure 3-6 is the equivalent circuit of the peak detector and low-pass filter. Assume Rs << R_1 and resistance of the reverse biased diode is much greater than R_1. Then the charging time constant of the peak detector is given by Equation 3-4.

$$Tc = Rs \times C \tag{3-4}$$

$$\leq 10.5\,\mu sec.$$

The frequency response of the peak detector during charging period will be similar to Figure 3-5. The 3 db cut-off frequency is given by Equation 3-5.

$$f_c = \frac{1}{2\pi Tc} \tag{3-5}$$

$$= (2\pi \times 10.5 \times 10^{-6})^{-1}$$

$$= 15.1 \text{ K.Hz}$$

The noise bandwidth of this system is greater than 15.1 K.Hz but less than 30 K.Hz. As in the average detector, to provide ripple free correction voltage Vdc to the second chrominance amplifier, a large discharge time constant of one second is selected. On comparing the noise bandwidth of the peak detector with the average detector, it is found that the peak detector noise bandwidth is about 3000 times as great as average detector. Therefore, the peak color level control system in its simple form can not be used, because the presence of noise in the signal will badly effect the color level.

In order to use the peak color level control the noise must be stopped before it reaches the peak detector. Also on comparing the charge time constant of the peak detector, which is about 10 μsec, with the discharge time constant of the peak detector, which is about one second, it is found that peak detector is unidirectional. That is, the correction voltage Vdc will follow an increase of color level at a much faster rate than a decrease of color level. In fact, the discharge time constant of one second is so long that a sudden decrease in the chrominance signal amplitude will be followed only after a delay that can be seen on the screen by a viewer. A long discharge time constant is desirable for a ripple free correction voltage, but it makes the correction voltage response to the decrease in chrominance signal very slow. An advanced and practical peak color level control which avoids the above disadvantages has been developed, and will be discussed in next section.

Performance Of Peak Color Level Control.

The objective of the peak color level control, as the name implies, is to maintain the peak level of the chrominance signal level at the input of the chrominance demodulator at a constant level. The merit of the system will be determined by its ability to handle various scenes ; this is for the same reasons as were given in the (3-3) " Performance of average color level control." Let it be assumed that an average color scene has some saturated color object, and under such conditions, the peak color level control system provides the d.c voltage equal to Vdc to the second chrominance amplifier. Let the error in the correction voltage, due to change of the color scene from the defined average color scene, be ΔVdc.

Table 3-2

Type of Color Scene	Correction Voltage
Highly saturated color scene	Vdc
Lightly saturated color scene	Vdc
Highly unsaturated color scene	Vdc $- \Delta$Vdc
Average unsaturated color scene	Vdc $- \Delta$Vdc
Lightly unsaturated color scene	Vdc $- \Delta$Vdc

Comparing Table 3-2 with 3-1, we note that peak color level control provides the constant correction voltage Vdc for the scenes (1) Highly saturated color scene (2) Lightly saturated color scene. In contrast, the average color level control changed correction voltage as the average color saturation changed. But with the peak detector there is an incorrect feedback voltage when there is no saturated color peak. However, since the burst amplitude is about 55 % of the chrominance amplitude representing a saturated color object, the correction error, ΔVdc, introduced by the system is limited to the value which will make the burst amplitude at the input to the chrominance demodulator equal to the amplitude of the chrominance signal of a saturated color object.

3-5 An I.C. Approach To The Peak Color Level Control :

Because of the complexity of the peak color level control system, an integrated circuit system is considered to be the most economical. The peak color level control system was designed to meet the following objectives.

(1) Maintain the peak amplitude of the chrominance signal at the input of the chrominance demodulator at a constant selected level.

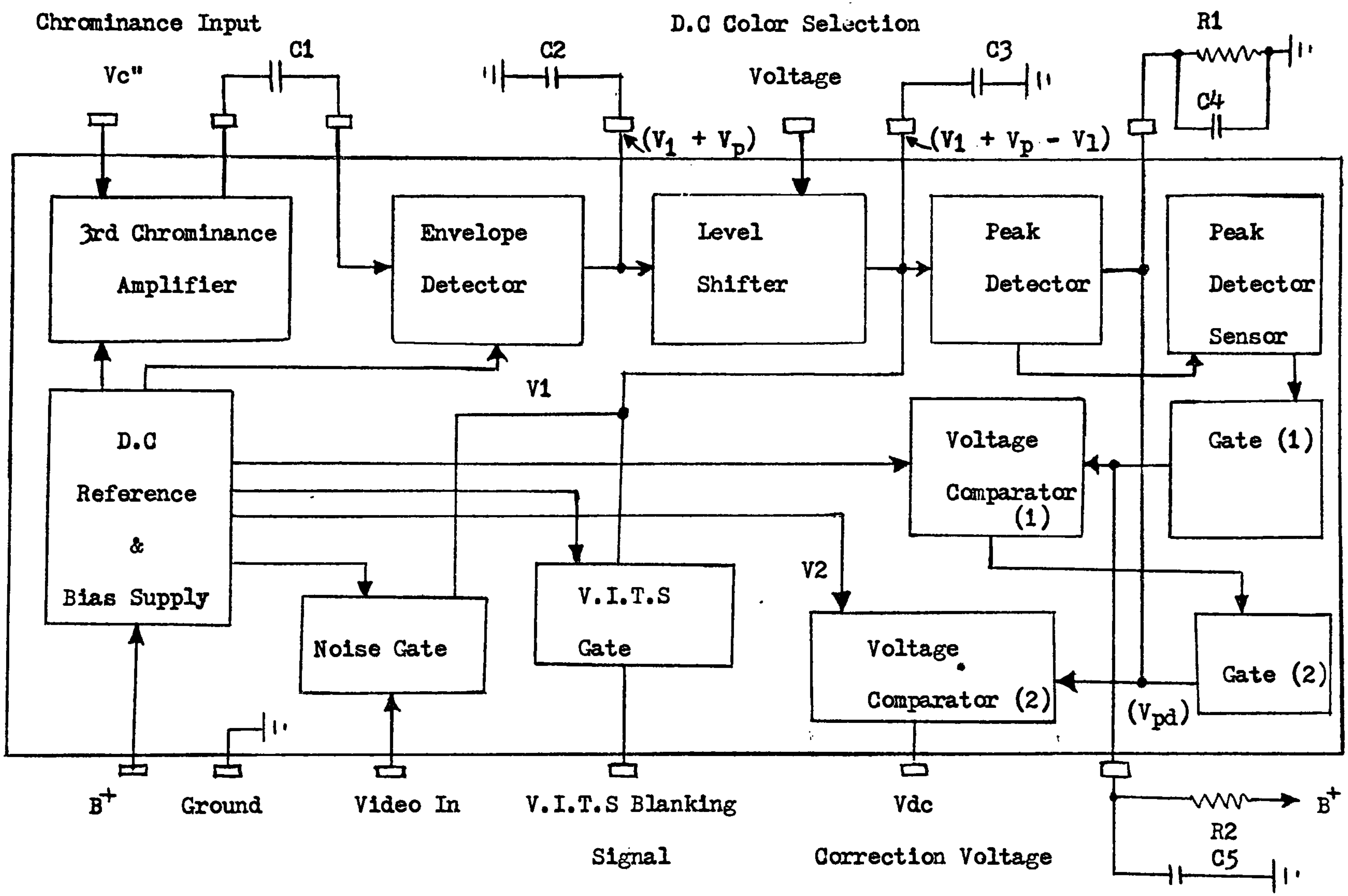
(2) Provide a means for the chrominance amplitude selection. This is the selected level of the chrominance amplitude which the system will maintain at the input to the chrominance demodulator.

(3) Provide noise protection for the peak detector.

(4) Provide gating to eliminate unwanted signals. Unwanted signals are those chrominance signals which are not related to the color scenes. For example, vertical interval test signals which networks or stations transmit on lines 14 to 18.

(5) Sample and hold scheme to reduce the discharge time constant of the peak detector, still providing ripple free correction voltage Vdc.

The system diagram of the integrated circuit performing the above mentioned objectives of the peak color level control is shown in Figure 3-7. The chrominance signal at input to the chrominance demodulator is applied to the input of the chrominance amplifier. This is the third chrominance amplifier, and it is part of the peak color level control system. The output of this amplifier is a.c coupled to the enveloped detector, which is biased with a d.c reference voltage V_1. The output of the envelope detector, therefore, is a positive half envelope of the chrominance signal and d.c reference signal V_1. Let the color level selection be made so that the peak amplitude of the



SYSTEM DIAGRAM OF AN INTEGRATED CIRCUIT FOR PEAK COLOR LEVEL CONTROL

Figure 3-7.

chrominance signal of a saturated color object is Vp. Then the output of the envelope detector Ed(sat) for saturated color is given by Equation 3-6.

$$\text{Eed (sat)} = Vp + V_1 \qquad (3\text{-}6)$$

Let it be assumed that for this condition, the level shifter introduces a d.c voltage shift of Vl. This is due to the peak color level selection made by applying a d.c voltage to the input of the level shifter. The output of the level shifter, Els, for saturated color is given by Equation 3-7;

$$\text{Els (sat)} = Vp + V_1 - Vl \qquad (3\text{-}7)$$

The peak detector detects the peak amplitude of the signals and therefore its output Vpd is a d.c voltage which is given by Equation 3-8.

$$Vpd = Vp + V_1 - Vl \qquad (3\text{-}8)$$

The output of the peak detector Vpd is compared with a reference voltage V_2 in a high-gain voltage comparator. The output of the voltage comparator is the correction voltage Vdc, which controls the gain of the second chrominance amplifier. Therefore, if closed the loop gain is very high, the peak detector output Vpd approximatly equals the reference voltage V_2.

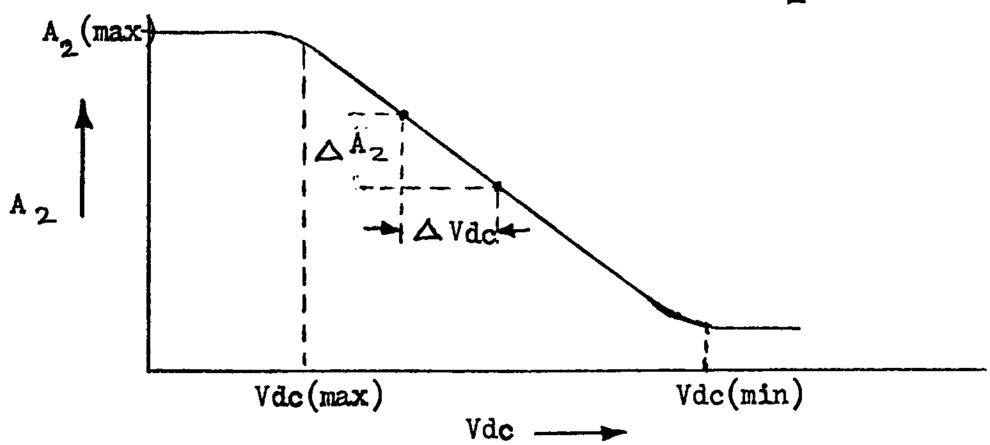
$$Vpd = Vp + V_1 - Vl \cong V_2 \qquad (3\text{-}9)$$

If $V_1 = V_2$,

then $Vp \cong Vl$ (3-10)

Equation 3-10 is the foundation of the peak color level control system; it implies that the peak amplitude of the chrominance signal of a saturated color object should be equal to the d.c voltage shift V1 introduced by the level shifter. Once the value of V1 is selected by applying a d.c voltage to the level shifter, the chrominance amplitude of the saturated color should be equal to that value. This expression does not involve the chrominance signal amplitude at the input of the second chrominance amplifier. Therefore, within the limits of the second chrominance amplifier gain, the chrominance signal amplitude at the output of the third chrominance amplifier, and therefore also at the output of the second chrominance amplifier, is independent of the chrominance signal amplitude at the input of the second chrominance amplifier. Therefore this system will maintain the peak amplitude of the chrominance signal of a saturated color object at a selected level. Since this is achieved by a d.c correction voltage Vdc, the chrominance signal amplitude of the unsaturated color objects will maintain their proper amplitude relationship with the saturated color object.

Figure 3-8, exhibits the relationship between the control voltage Vdc and second chrominance amplifier gain A_2.



SECOND CHROMINANCE AMPLIFIER GAIN A_2 Vs CONTROL VOLTAGE Vdc

Figure 3-8

$$A_2 = A_2(max) - K\,Vdc \qquad (3\text{-}11)$$

-for Vdc (max) $\leqslant$ Vdc $\leqslant$ Vdc(min)

Where K is the change in voltage gain of the second chrominance amplifier for one volt change in Vdc.

Therefore :

$$\Delta Vdc = \frac{-\Delta A_2}{K} \qquad (3\text{-}12)$$

A relationship between Δ Vdc given by Equation 3-12 and Δ Vc", the change in chrominance amplitude at the output of the second chrominance amplifier, will now be established. Let the gain of the voltage comprator be called Avc. Then the change in peak detector output ΔVpd, to cause a change of ΔVdc, is given by Equation 3- 13.

$$\Delta Vpd = \frac{\Delta Vdc}{Avc} \qquad (3\text{-}13)$$

Since V_1 and V_2 are constants, and V1 is constant for a given selection, then from Equation 3-9,

$$\Delta Vpd = \Delta Vp = \frac{\Delta Vdc}{Avc} \qquad (3\text{-}14)$$

and

$$\Delta Vc'' = \frac{\Delta Vp}{k\,A_3} = \frac{\Delta Vp}{.5\,A_3} \qquad (3\text{-}15)$$

The constant k is equal to .5 to compensate for a loss of 50 % in chrominance peak amplitude at the envelope detector, because it only forms a positive or negative half envelope of the chrominance signal Vc". The voltage gain of the third chrominance amplifier is A_3. From Equations 3-14 and 3-15 we get Equation 3-16.

$$\Delta Vc'' = \frac{\Delta Vdc}{.5\,A_3\,Avc} \qquad (3\text{-}16)$$

Substituting the value of Δ Vdc from Equation 3-12,

$$\Delta Vc'' = \frac{-\Delta A_2}{.5\ A_3 Avc\ K} \tag{3-17}$$

The maximum error in the output chrominance amplitude will be for the error in the input chrominance amplitude which will cause the gain of the second chrominance amplifier to change from zero to maximum gain. That is,

$$\Delta A_2 = A_2(max).$$

$$\Delta Vc''\ (max) = \frac{-A_2(max)}{.5\ A_3 Avc\ K} \tag{3-18}$$

Therefore, the chrominance amplitude error at the output of the second chrominance amplifier can be minimized by making K, Avc and A_3 large and A_2(max) small. However A_2(max) also determines the maximum value of chrominance amplitude change at the input of the second chrominance amplifier that the system will be able to correct. Therefore a compromise is made in the selection of A_2(max), such that the second chrominance amplifier gain is not reduced too much in order to reduce ΔVc" (max).

Chrominance Amplitude Selection.

The chrominance signal amplitude at the output of the second chrominance amplifier is selected by introducing a d.c voltage shift at the input of the peak detector. The peak amplitude of the chrominance envelope at the input of the level shifter is given by Equation 3-19,

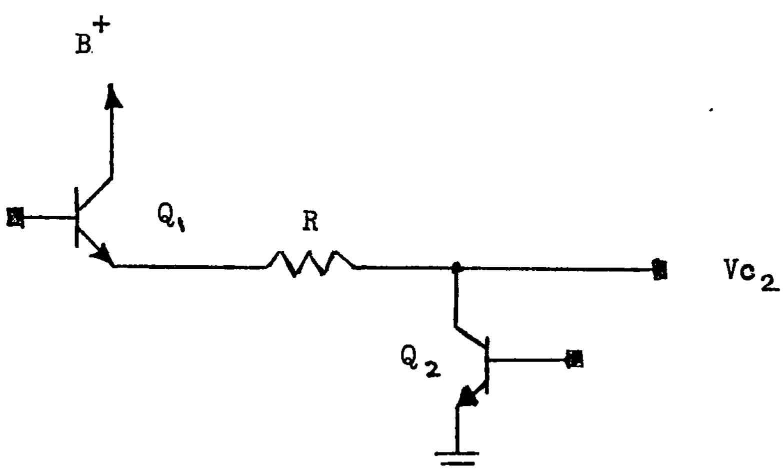
$$Ep = Vc'' \times A_3 \times .5 \tag{3-19}$$

where A_3 is the gain of the third chrominance amplifier. The expression on the right side of the Equation is multiplied by 0.5 because envelope detector only detects one side of the chrominance envelope. Substituting the value of Ep from Equation 3-10 in to Equation 3-19, we obtain the expression for Vc".

$$Vc'' \cong V1\ (A_3 x\ .5)^{-1} \qquad (3\text{-}20)$$
$$= C \times V1$$

C is a constant.

Selecting V1 is equivalent to selecting the chrominance amplitude at the output of the second chrominance amplifier. There are various types of d.c voltage level shifter circuits known in the I.C. technology. Figure 3-9 is a very simple circuit of a d.c voltage level shifter.



D.C VOLTAGE LEVEL SHIFTER

Figure 3-9.

If the signal at the emitter of the transistor Q_1 is V_1 + Vp and the collector current of Q_2 is Ic_2, then the signal at the collector of Q_2, with reference to ground, is given by Equation 3-21.

$$Vc_2 = V_1 + Vp - Ic_2R \qquad (3\text{-}21)$$
$$= V_1 + Vp - Vl$$

Where Ic_2R is equal to Vl and Vl is the voltage level shift introduced by the collector current of Q_2. By selecting the collector current of Q_2, one can select the Vl, and therefore Vc".

Noise Protection Of The Peak Detector.

It was shown earlier that the peak detector noise bandwidth is very large compared to that of an average detector. Therefore the peak color level control using peak amplitude detection of the chrominance signal is not practical unless the peak detector is protected from noise. Noise signals are picked up at the antena and, through R.F and I.F amplifiers, arrives at the video detector. There it is present with the luminance and chrominance signals. From Figure 2-1(a) which is photograph of a voltage waveform of a composite video signal, it is seen that the most negative part of the signal is the sync tip at - 40 I.R.E. units, and the most negative part of the chrominance signal is the burst tip at - 20 I.R.E. units. Therefore one can define any signal more negative than - 20 I.R.E. units as a noise signal.

The chrominance envelope signal at the input to the peak detector is time delayed in relation to the chrominance signal at the video detector. This time delay in the chrominance envelope is due to the narrow bandwidth of chrominance band-pass filters and also to the further time delay introduced in the envelope detector. The level shifter impedance and capacitor C_3 also introduce some time delay. Therefore, noise at the input of the noise gate is ahead of the noise arriving at the input to the peak detector. The noise gate compares the video with a reference voltage equivalent to - 20 I.R.E. level. Any time a noise signal is present, it will go below - 20 I.R.E. level. Because in general, noise signals are of a much higher amplitude than the video signal. The noise signal amplitude is only limited by the R.F and I.F amplifier gain. The presence of noise will turn on the noise gate, which will discharge the capacitor C_3 and will turn off the input of the peak detector. At the end of the noise signal at the noise gate, the noise gate will turn off. Since it takes some time to charge capacitor C_3, due to impedance of level shifter, the input of the peak detector stays well below its normal level. This insures that a noise signal which arrived late at this input due to time delay has completly gone before the input to the peak detector reaches the active level.

Vertical Interval Test Signals Gate.

The first 19 lines of the television signals do not carry any video information, except for horizontal and vertical synchronization information. Television stations and networks utilise this period by sending test signals that are not related to the perticular television program being transmitted. The signals are useful in evaluating the transmission system and other signal processing equipments at the station. Since these test signals may be inserted at any point in the system, they do not provide a good reference for chrominance amplitude and must be removed from the peak color level control system.

A vertical blanking pulse, wide enough to include line 1 through line 19, is applied at the input of the V. I. T. S. gate. The gate, in presence of this pulse, turns on and discharges the capacitor C and pulls the input of the peak detector to ground potential. This prevents the V. I. T. signals from influenceing the peak detector.

Discharge Time Constant Of The Peak Detector.

The peak detector's charge time constant is much smaller than its discharge time constant. The charge time constant of the peak detector was found to be less than 10.5 μs, whereas discharge time constant of one second or more is considered suitable to provide ripple free correction voltage Vdc. This long discharge time constant makes the system slow in providing the correction voltage in case the chrominance signal amplitude suddenly decreases. The peak color level control system utilises the sample and hold hold technique to decrease the time the system takes in providing correction voltage for decreasing chrominance signal amplitude, while still keeping the large discharge time constant to provide ripple free correction voltage Vdc.

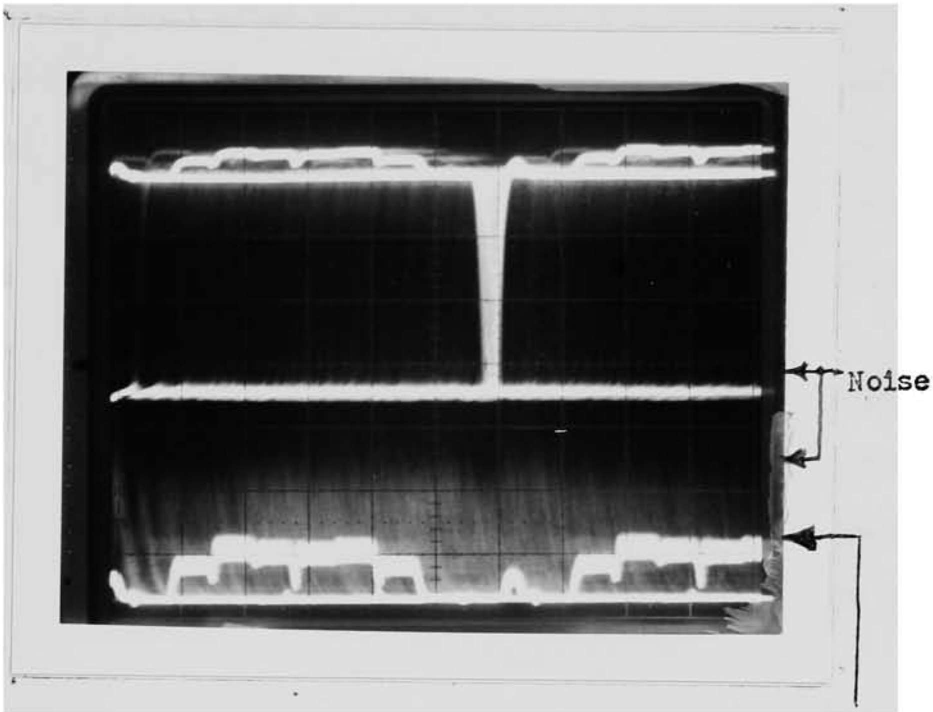
Refering to Figure 3-7, capacitor C_4 holds the peak detector's d.c voltage. In a normal operation, the peak detector will supply the charge to the capacitor C_4. Discharge time constant $R_1 C_4$ is very large. Still, the small amount of charge lost by the capacitor C_4 must be supplied by the peak detector. The peak detector sensor detects this operation of the peak detector and keeps the gate 1 on, which keeps the capacitor C_5 discharged. The voltage comparator output for this condition of C_5, keeps the gate 2 off and lets the capacitor

C_4 retain its charge.

If the input of the peak detector suddenly drops because the chrominance signal amplitude has decreased suddenly, the peak detector will not provide any charge to the capacitor C_4. It will wait for capacitor C_4 to discharge through R_1 to the new level at which peak detector again has to supply charge. Since R_1 is large, C_4 will take long to discharge to this new level. But the peak detector sensor turns the gate 1 off as soon as peak detector stops supplying charge to C_4. This causes the capacitor C_5 to charge through the resistor R_2. The charge time constant $R_2 C_5$ is selected such that in ten frames, in about 150 m sec, the voltage at the input of the voltage comparator will reach a level to provide an output for gate 2, which now turns on, providing an instant discharge of C_4 to the level where peak detector again starts supplying the charge. This is sensed by the peak detector sensor which turns on the gate 1, instantly discharging the capacitor C_5, and the voltage comparator turns the gate 2 off. Therefore C_4 only discharges to a new level, and in a much shorter time than otherwise was possible by its discharge through R_1.

Performance of the Integrated Circuit.

The integrated circuit discussed above, was built and worked satisfactorily in meeting its objectives. The most important reason for constructing this integrating circuit was to provide noise protection to the peak detector. It was shown earlier, see subheading 3-4, Peak color level control, that a peak detector for color level control performs better than average detector, but its noise bandwidth



Envelope of the chrominance signal.

UPPER WAVEFORM :

ENVELOPE OF THE CHROMINANCE SIGNAL AFTER NOISE PROTECTION.

LOWER WAVEFORM :

ENVELOPE OF THE CHROMINANCE SIGNAL BEFORE NOISE PROTECTION.

Figure 3-10.

of about 15 K.Hz made it unusable for accurate peak color level control. Figure 3-10, which is a photograph of the voltage waveforms, shows the envelopes of the chrominance signal. The upper waveform shows the envelope of the chrominance signal after noise protection, and the lower waveform shows the envelope of the chrominance signal before noise protection. The photograph clearly shows that the noise is going above the chrominance envelope in the unprotected envelope, whereas the same noise is going downward in the chrominance envelope protected with noise gate. Therefore, the peak detector detecting the chrominance envelope after noise protection will not be influenced by the noise. The upper voltage waveform of the chrominance envelope is taken at the output of the level shifter (see Figure 3-7), and the lower voltage waveform of the chrominance envelope is taken at the output of the envelope detector or at the input of the level shifter.

IV. AUTOMATIC HUE CORRECTION

4-1 Introduction :

The hue or tint information of a colored object is transmitted as the phase of the chrominance signal with respect to the burst phase. The color circle shown by Figure 2-5 (a) is a vector presentation which displays the relative phase and amplitude of the chrominance signal of N.T.S.C. color bars. It was shown earlier, in subheading 2-4, that the burst is used to generate the C.W reference signals which are used for the demodulation of the chrominance signal at the receiver. Therefore, signal source distortion (refer subheading 2-5), which causes " Chrominance phase to burst phase reference distortion " will also cause the colored object being reproduced at the receiver to be in the wrong hue. There are several sources of this distortion.

(1) F.C.C. specifies the phase tolerance between burst and chrominance as $\pm 10^{\circ}$.

(2) Differential phase introduced by some transmitters in their video transmitter. In particular, nonlinearity at the heigher power levels can result in the burst being modified in phase with respect to the chrominance signal phase. This will produce nonuniformity in color hue reproduction between various transmitters.

(3) Static phase error, introduced by the receiver in the generation of the two C.W reference signals, and used for the demodulation of the chrominance signal.

Just as in the case of signal source distortion relative to the chrominance amplitude, an attempt to correct this distortion will introduce more distortion. This is caused by the lack of a correct phase reference for the chrominance signal.

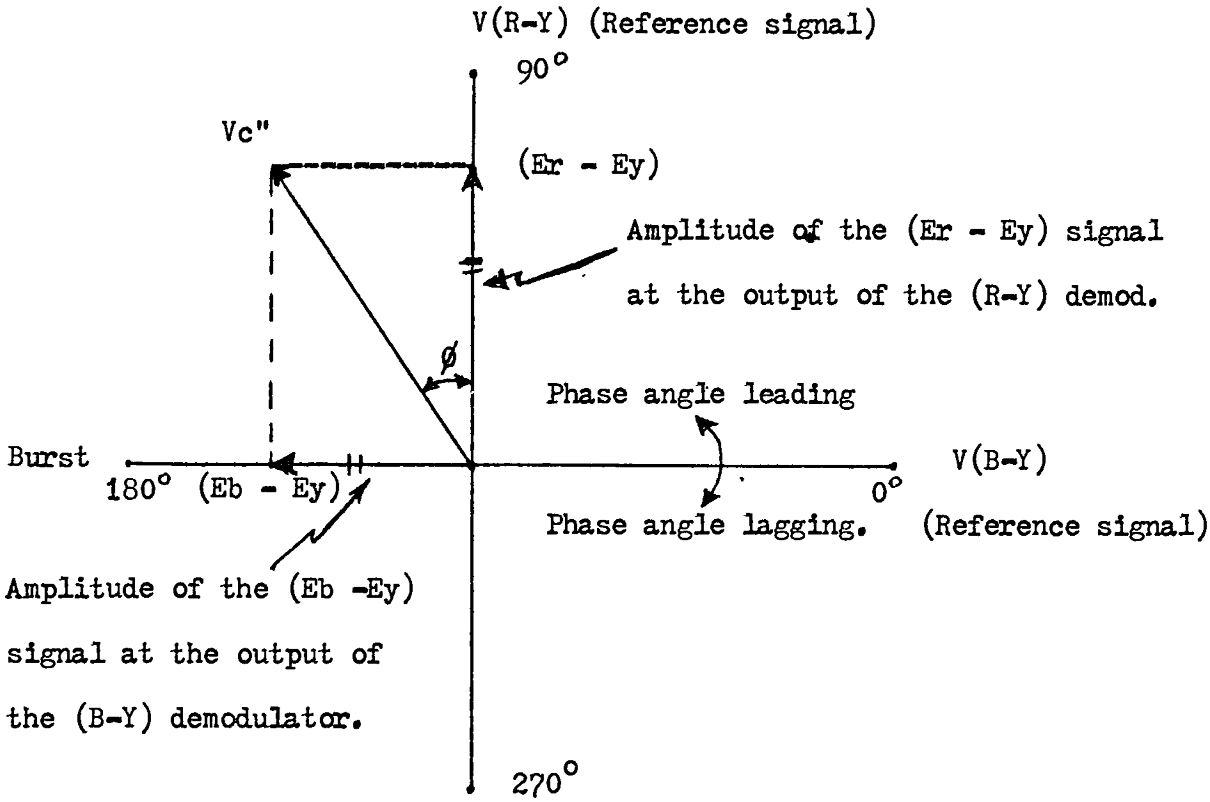
The objective of the automatic hue correction is to reduce the hue variation in the fleshtone region, which is caused by the signal source distortion related to phase. There is more concern with the hue near the fleshtone region because of our memory and ability to recognise such colors. For example, everyone knows that human flesh can not be normally yellow- green or purple, whereas one does not know about or is not as critical of the hue of other objects such as automobiles, dresses, room walls etc.

However, our ability to recognise certain objects and their proper hue is not limited to human flesh. Certain other objects seen in every day life, such as the sky, trees, etc, have familiar hues. Everyone knows that the sky can not be green and a tree is not normally blue. Because of the signal source distortion, there is no useful reference to the receiver. It can not, therefore, correct the hue of every scene. Since fleshtones are statistically more common than most other hues, it is reasonable to modify all of the colors between yellow-green and purple to approximate flesh colors. Then for most practical purposes, the picture will be more acceptable to the viewer.

4-2 Quadrature Distortion In Synchronous Detectors And Its Effect On Hue :

Two synchronous detectors are used to detect the (Er - Ey) and (Eb - Ey) color difference signals from the composite chrominance signal. The two reference C.W signals, namely, the V(R-Y) signal to detect (Er - Ey) signal and the V(B-Y) signal to detect (Eb - Ey) signal, are in quadrature phase with each other. It is important to maintain an accurate phase relationship between the reference signals, V(R-Y) and V(B-Y), and the burst in the chrominance signal for proper hue presentation of colored object on the C.R.T. screen. At the transmitter, the two color difference video signals were modulated with two C.W color subcarrier signals in quadrature phase with each other. Therefore at the receiver, the two C.W subcarrier reference signals V(R-Y) and V(B-Y) must be in quadrature phase with each other so that colors of the scene are reproduced with full color fidelity and accuracy. However, it has been observed that by increasing the angle between the V(R-Y) and V(B-Y) signals, one can reduce the color fidelity. This is desirable for colors in region of fleshtone because it makes the hue error due to signal source distortion more acceptable to the viewer. But it is done at the expense of hue distortion of the other colors.

Figure 4-1 vectorially describes the operation of two synchronous detectors. The (R-Y) demodulator detects the (Er - Ey) color difference signal by phase detecting the chrominance signal, Vc", with reference to the V(R-Y) subcarrier. Similarly the (B-Y) demodulator detects the (Eb - Ey) color difference signal by phase detecting the chrominance signal, Vc", with reference to the V(B-Y) subcarrier reference. If Vc" is leading V(R-Y) subcarrier reference signal by an angle ϕ, then the output of the (R-Y) demodulator after the low-pass filter will be equal to $\frac{1}{2}$ (Er - Ey) Cos ϕ. In Figure 4-1, this is equal to the length projected from the chrominance signal vector Vc" on the V(R-Y) axis. Similarly it can be shown that output of the (B-Y) demodulator after low-pass filter will be equal to the length projected by Vc" on the V(B-Y) axis.



VECTOR REPRESENTATION OF (R-Y) AND (B-Y) DEMODULATORS

Figure 4-1.

The angle between V(R-Y) and V(B-Y) can be increased by making a leading phase shift to V(R-Y) reference signal and a lagging phase shift to V(B-Y) reference signal. Figure 4-2 demonstrates the effect on various colors of increasing the phase angle between the two reference signals from 90° to (90 + 2 øe) degrees. In Figures 4-2 to 4-5 the following vectors will be used :

O A ---- Output of the (R-Y) demodulator with original reference V(R-Y).

O A'---- Output of the (R-Y) demodulator with new reference V'(R-Y).

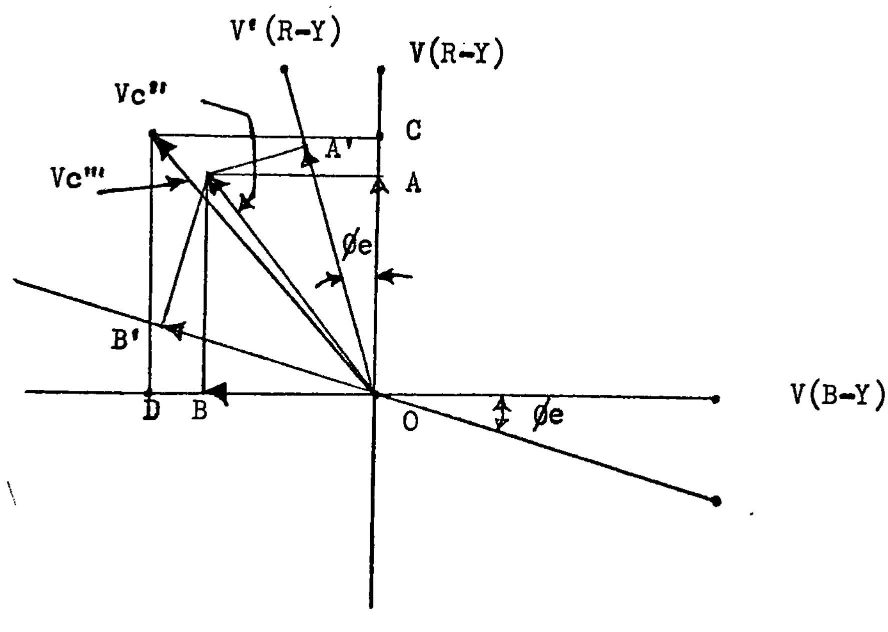
O B ---- Output of the (B-Y) demodulator with original reference V(B-Y).

O B'---- Output of the (B-Y) demodulator with new reference V'(B-Y).

O C ---- Vector on the V(R-Y) axis of length O A'.

O D ---- Vector on the V(B-Y) axis of length O B'.

(a) Fleshtone color (approximatly orange).

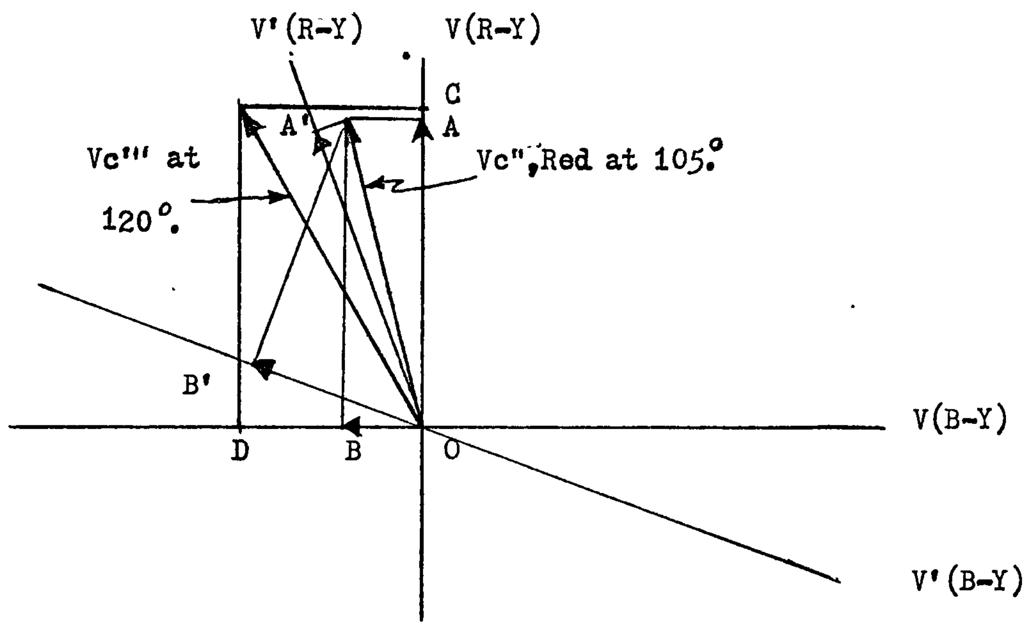


EFFECT OF QUADRATURE DISTORTION ON FLESHTONE COLORS

Figure 4-2.

Therefore the Vc" chrominance signal with new references V'(R-Y) and V'(B-Y), will give outputs equivalent to Vc''' chrominance signal with proper reference V(R-Y) and V(B-Y). For fleshtone colors the wider phase angle between the reference signals, which is quadrature distortion, is equivalent to increasing the amplitude of the chrominance signal and slightly phase shifting it in the leading direction.

(b) Red colors.

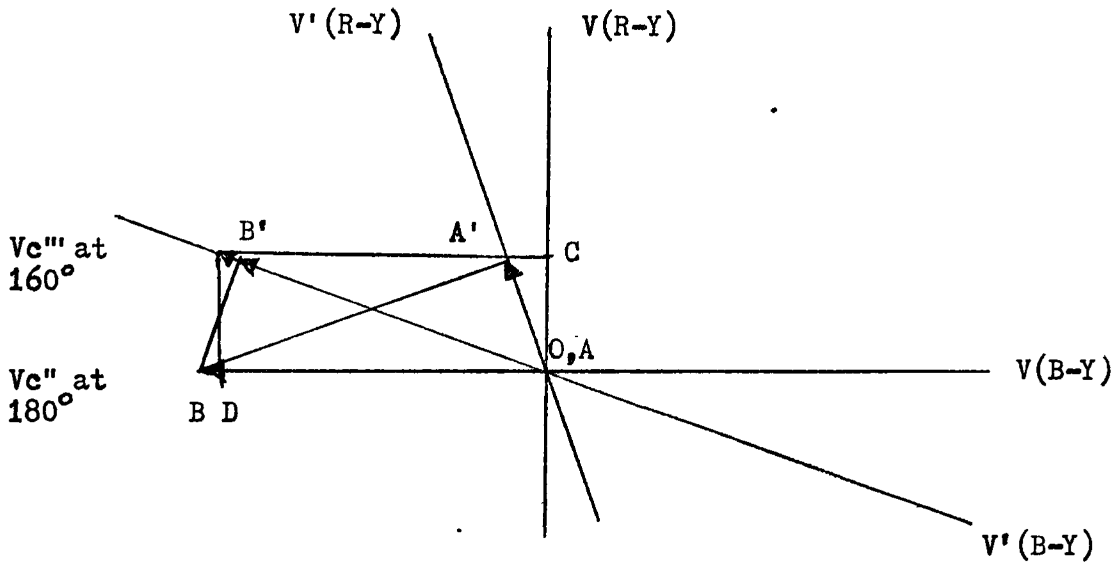


EFFECT OF QUADRATURE DISTORTION ON RED COLORS

Figure 4-3.

Therefore, the outputs from the two demodulators, having quadrature distortion, when the chrominance signal represents red color, will be equivalent to the outputs from the demodulators having no quadrature distortion when the chrominance signal represents fleshtone colors. Therefore at the receiver which uses quadrature distortion in the demodulators, the red colors will be detected as fleshtone colors.

(c) Yellow - Green colors.



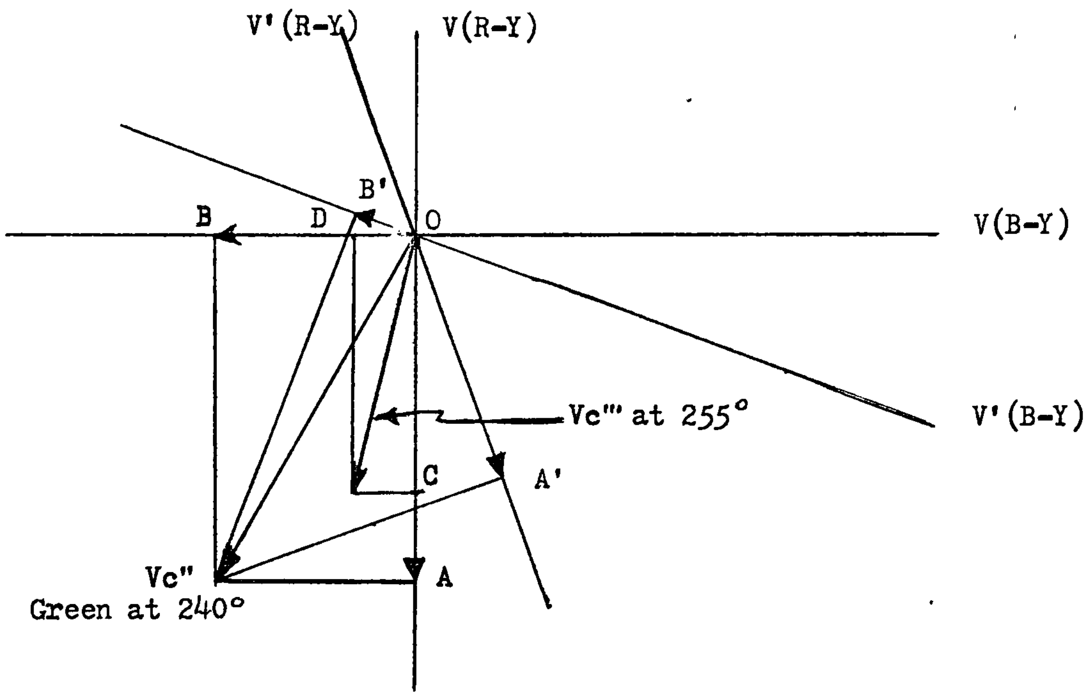
EFFECT OF QUADRATURE DISTORTION ON YELLOW - GREEN COLORS

Figure 4-4.

The chrominance signal for yellow-green colors does not normally have an output from (R-Y) demodulator, (O A = 0). But because of quadrature distortion, there is an output from the (R-Y) demodulator. Therefore, the yellow-green color is detected as color approaching fleshtone color.

(d) Green colors.

Because of quadrature distortion, the chrominance signal for green color will produce outputs, from both the (R-Y) and the (B-Y) demodulators, as shown by Figure 4-5. This output will be equivalent to the chrominance signal having reduced in amplitude and which is shifted towards cyan. Therefore at the receiver, green colors will be reduced in amplitude and shifted towards cyan.



EFFECT OF QUADRATURE DISTORTION ON GREEN COLORS

Figure 4-5.

Similarly it can be shown that, because of quadrature distortion, magenta color will be reduced in amplitude and shifted towards blue. It is observed that the effect of the quadrature distortion which is intentionally introduced in the color demodulation system is to reduce its ability to produce true colors in full fidelity. For example, red and yellow-green colors will be reproduced as colors approaching fleshtone colors. This will ensure reproduction of human faces in correct color in the presence of hue error due to the signal source distortion which otherwise would have been produced in yellow-green or red colors. Therefore quadrature distortion results in the reduction of the fleshtone variation caused by the inaccurate relationship between burst phase and chrominance phase . However there are some undesirable effects of quadrature distortion. For example, there will be a reduction of the green and magenta colors and many other colors will not be produced accuratly.

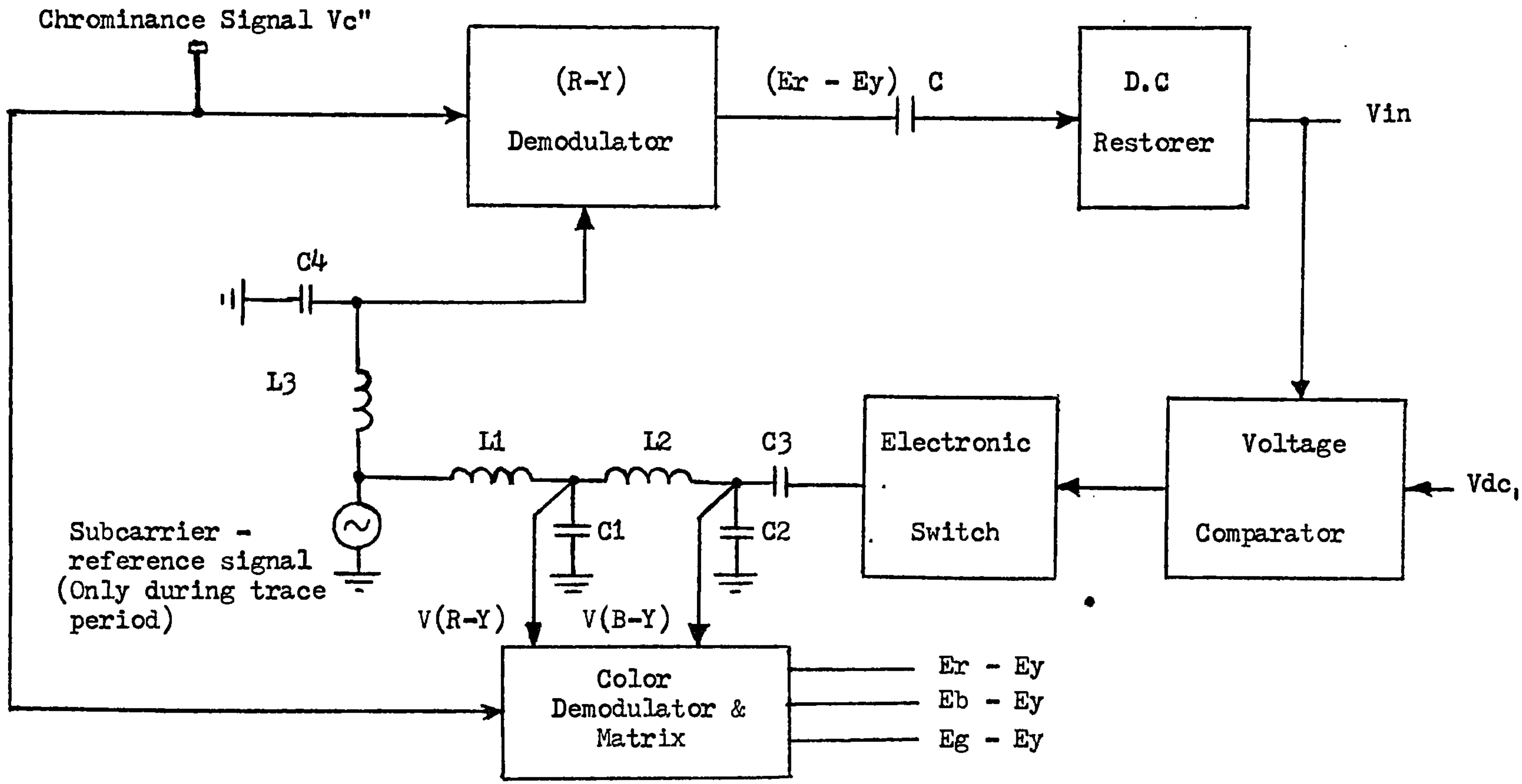
The gated system of quadrature distortion, which will result in the reduction of fleshtone variation, will be described next. It will reproduce some of the other colors like green, cyan etcetra correctly.

4-3 Gated Quadrature Distortion :

The effect of quadrature distortion on the demodulation of various colors has been shown. While it may be desirable to introduce this distortion to reduce fleshtone variation, there are undesirable affects on some other colors, such as green and cyan.

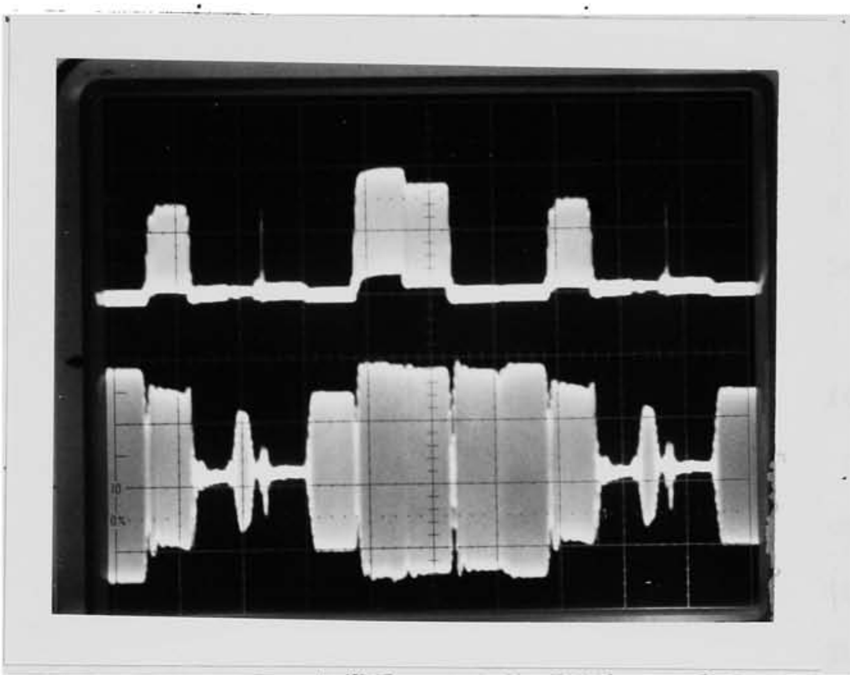
One notes from Figure 4-2 to 4-5 that colors in the range of yellow, green to red provide a positive output from the (R-Y) demodulator. Therefore this information can be used to determine when to introduce the quadrature distortion and when it would be undesirable to do so. Suppose there is an electronic switch such that whenever output of the (R-Y) demodulator is positive the switch is on and whenever the output of the (R-Y) demodulator is negative the switch is off. The on position of the electronic switch introduces the leading phase shift to the V (R-Y) reference signal. Its new location on the vector diagram in Figure 4-2 to 4-5 is then V' (R-Y). Similarly, a lagging phase shift is introduced in the V(B-Y) signal, and its new location on the vector diagram is V'(B-Y). The off position of the electronic switch does not introduce any phase shift to either of the two reference signals. Therefore, there is quadrature distortion for positive output of the (R-Y) demodulator and no distortion for negative output of the (R-Y) demodulator. The color fidelity has been improved for colors providing negative output from the (R-Y) demodulator. The system just described is known as "Gated Automatic Hue Correction" and is illustrated in Figure 4-6.

The output of the (R-Y) demodulator during horizontal retrace period is a d.c voltage known as quiescent voltage of the demodulator. During the horizontal trace period, in the presence of the chrominance signal, the (Er - Ey) video signal is at this quiescent voltage. The d.c restorer restores the quiescent voltage of the (Er -Ey) video signal at Vdc_1. Vdc_1 is also the value of the d.c reference of the voltage comparator. For positive (Er - Ey) signal, the input voltage, Vin, of the voltage comparator increase with respect to Vdc_1, and the output of the voltage comparator turns the electronic switch on. But, for negative (Er - Ey) signal, the input voltage, Vin, decreases with respect to Vdc_1, and the output of the voltage comparator turns the electronic switch off. The electronic switch is on for (Er - Ey) equal



GATED AUTOMATIC HUE CORRECTION SYSTEM

Figure 4-6.



YELLOW CYAN GREEN MAGENTA RED BLUE BURST

GATED AUTOMATIC HUE SWITCH & N.T.S.C COLOR SIGNAL

Figure 4-7.

to zero because then Vin is equal to Vdc_1. The on position of electronic switch puts C3 in parallel to C2, and this causes V(B-Y) reference signal to lag more in phase with respect to V(R-Y) than when electronic switch was off and C3 was not in parallel to C2. The new location of V(B-Y), when electronic switch is on, is V'(B-Y). The capacitor C3 going in parallel to C2 also increases inductive loading across C1 because L2 is in series with (C2 + C3). This causes the V(R-Y) reference signal to become more leading in phase with respect to V(B-Y) than when the electronic switch was off. The new location of V(R-Y), when electronic switch is on, is V'(R-Y).

Figure 4-7 is the photograph of two electrical waveforms. The upper waveform is the photograph of the V(B-Y) signal at the output of the electronic switch. The bottom waveform is the N.T.S.C color bar's chrominance signal. From the upper waveform we observe that electronic switch is off for green, cyan and blue colors and on otherwise. This conclusion is based on the fact that, whenever electronic switch is on, the V(B-Y) reference signal at the switch will terminate to ground and therefore V(B-Y) signal can not be seen, and when electronic switch is off it will offer high impedance to ground and therefore V(B-Y) signal can be seen.

V VERTICAL INTERVAL REFERENCE SIGNAL.

5-1 Introduction :

It has been shown that all attempts to correct signal source distortion at the receiver, without a true reference, resulted in minimizing some distortions, but it also introduced some other distortions. The performance of the television receiver is degraded; a true receiver should reproduce the signals faithfully on the screen. No attempt should be made to alter the signal in absence of a reliable reference.

At the suggestion of the "Society of Motion Picture and Television Engineers" (S.M.P.T.E), a meeting of the "Joint Committee for Inter-society Coordination" (J.C.I.C) was called in 1968 to determine the most effective way to deal with this problem. The J.C.I.C, representing the "Electronic Industries Association" (E.I.A), the "Institute of Electrical and Electronic Engineers" (I.E.E.E), the "National Association of Broadcasters" (N.A.B) and the S.M.P.T.E, agreed that an ad hoc committee should be set up to :

(a) Examine the entire television system from the original scene, through all equipment, to the picture viewed in the home.

(b) Determine the origin of significant deviations in color in the received picture.

(c) Allocate to existing industry organizations questions for further investigation and resolution.

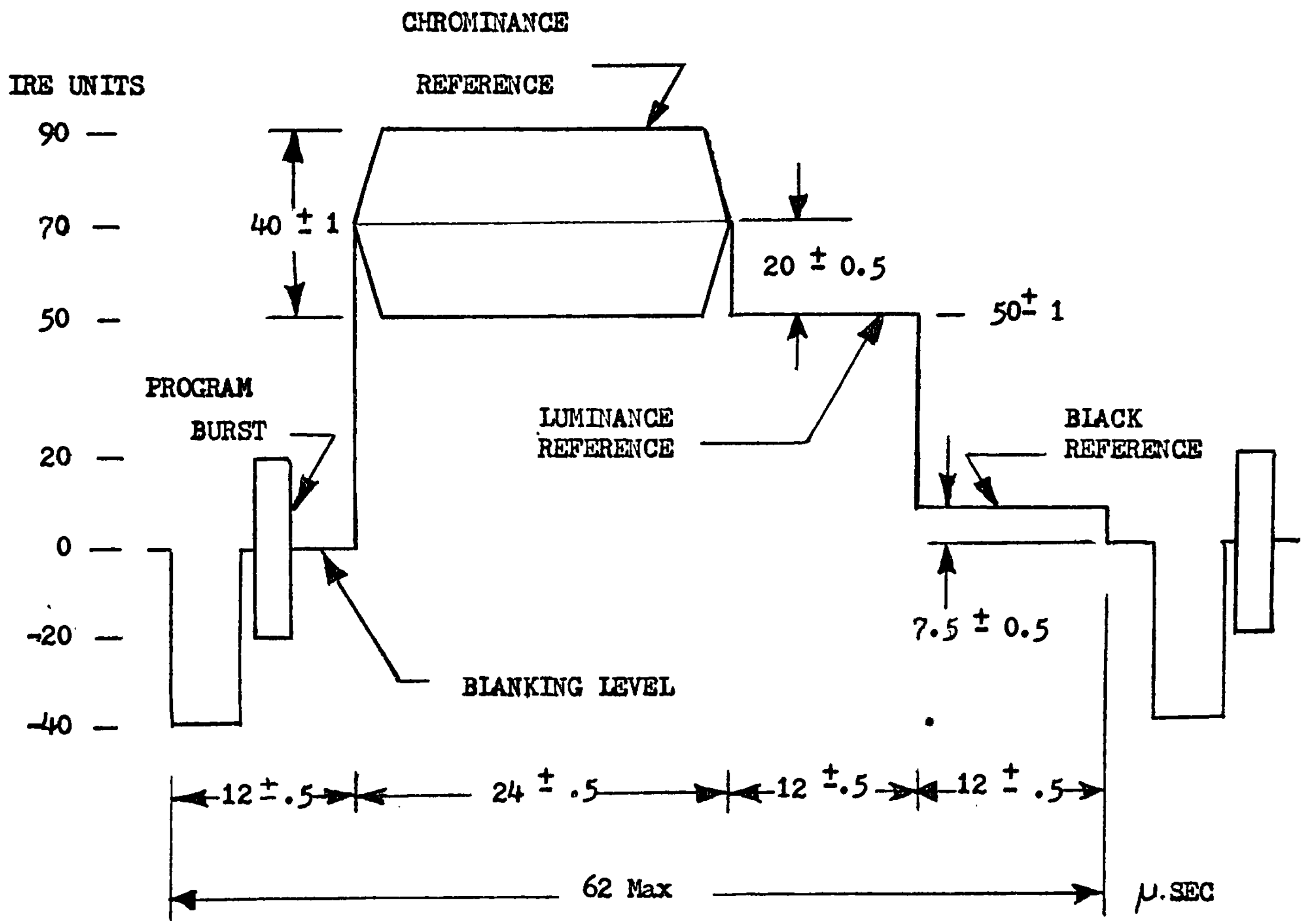
Further investigations, by J.C.I.C and "Broadcast Television Systems Committee" (B.T.S) of E.I.A , resulted in the development of a convenient reference signal through which, at locations distant from the point of program origination, the correct relationship between chrominance and burst amplitude and phase could be verified, and if necessary, reestablished. This reference signal, is known as the "VERTICAL INTERVAL REFERENCE SIGNAL" (V.I.R), is inserted during the vertical blanking interval of a television program signal. A V.I.R signal stays with a program signal from the point of addition to the final destination. The V.I.R signal is intended to be associated with a particular program. Therefore, the V.I.R signal should be added to the program signal at a point in the video system where the correct amplitude and phase of the composite color signal are established and the artistic judgement is made that color reproduction is as desired. Once the V.I.R signal is added in this manner, it represent a certification of, and a reference for, the program signal. After the V.I.R signal has been added to the video signal, it must be treated exactly like the video signal in all equipment through which it passes. When adjustments are made so that the V.I.R signal is correct at any point in the video system, the program will be reestablished at that point to the same characteristic as when it was initially certified.

5-2 The V.I.R Signal :

Figure 5-1 shows a drawing of the V.I.R signal waveform. The signal is inserted on line 20 on both television fields. The V.I.R signal provides following references.

(a) Chrominance reference.

The first 24 microseconds of the V.I.R signal is a chrominance reference of 40 I.R.E units peak-to-peak, superimposed on a luminance pedestal of



THE V.I.R SIGNAL

Figure 5-1.

70 I.R.E units. The phase and amplitude of the chrominance reference is the same as that of the color burst of the program signal. Having the amplitude and phase of the chrominance reference the same as those of the program color burst allows direct comparisons to be made between them.

(b) Luminance Reference.

Following the 24 microsecond chrominance reference, there is a 12 microsecond luminance reference at 50 I.R.E units. A luminance reference of 100 I.R.E units were not chosen for the V.I.R signal to insure that white compression would not affect the reference level. The choice of 50 I.R.E units also has the advantage that it is the same level as the lower edge of the chrominance reference bar. This permits a quick check of the relative chrominance to luminance ratio.

(c) Black Reference.

Following the 12 microseconds luminance reference, there is a black reference of 12 microseconds at a level of 7.5 I.R.E units. This is the nominal setup value. The presence of the black reference allows the proper black level to be reestablished whenever necessary.

The primary amplitude reference parameter of the V.I.R signal is the luminance reference. After the luminance reference has been established by adjusting overall signal gain, the black and chrominance reference levels of the V.I.R signal and the sync and burst levels of the program are adjusted with respect to the basic luminance reference. In this way, all amplitude parameters of a color television signal may be adjusted to have the proper relationship to each other.

The phase of the chrominance reference signal of the V.I.R signal, should be same as burst phase. The phase of the burst is compared with the chrominance reference signal phase and if necessary burst phase is adjusted to match the V.I.R chrominance reference signal phase. Once the above said adjustments are made to correct the V.I.R signal, the program will be reestablished, at this point, to the same characteristics as when it was initially certified. This is the only true automatic correction of the signal distortion, because we are correcting a signal of known characteristics and originating at the source of the program. The signal distortion should be corrected at the transmitter and the receivers should faithfully reproduce the received signal without any alterations.

References :

(1) Using the vertical interval reference signal.
Tektronix, Inc. Application notes No. 8.

(2) E.I.A Television Systems Bulletin No 1.
" E.I.A Recommended Practice for use of a Vertical Interval Reference (V.I.R) Signal."
E.I.A Engineering Department, July 1972.